Ontario Geological Survey

Study 19

Geochemical Exploration of

Early Precambrian Volcanogenic Sulphide Mineralization

in

Ben Nevis Township

District of Cochrane

By

W.J. Wolfe

1977

Ontario

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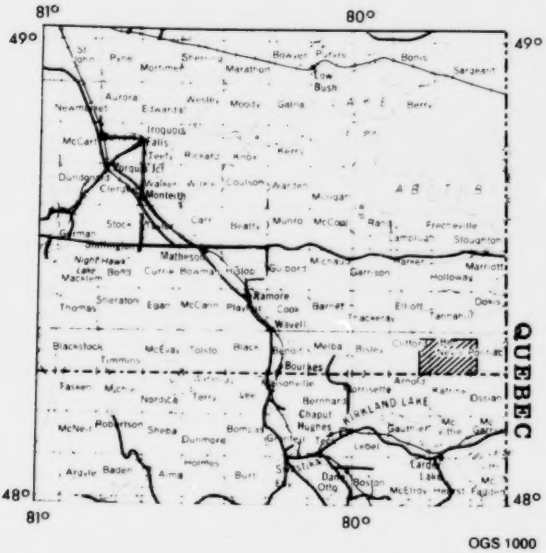
ABSTRACT

Zinc, copper, nickel, cobalt and manganese variations in Precambrian volcanic rocks have been mapped in detail in a 90 km² (35 square miles) test area situated in the central Abitibi Belt, 48 km (30 miles) west of Noranda, Quebec and 34 km (21 miles) northeast of Kirkland Lake, Ontario. Data collected from sites spaced with a mean density of 11 per km² (28 per square mile), are used to illustrate regional patterns of zinc, copper and nickel variability related to normal magma differentiation processes and residual patterns related to mineralizing processes.



1–Key map showing location of area studied. Scale 1:1,584,-000 (1 inch to 25 miles).

After subtracting the components of Zn and Cu variability attributable to systematic depletion of these elements with increasing SiO_2 and decreasing total Fe in differentiated basalt-andesite-dacite-rhyolite sequences, the residual Zn and Cu values provide a reliable guide to disseminated sphalerite-chalcopyrite mineralization in alteration pipes and haloes that surround volcanogenic massive sulphide deposits. Nickel, manganese and cobalt are not suitable indicators for Zn-Cu-Pb-Ag-Au sulphide deposits in the calc-alkaline volcanic environment of Ben Nevis Township. However, these elements are sensitive to changes in the bulk chemistry of the differentiated igneous rocks and are therefore useful in outlining major lithologic units. More limited data indicate that the elements arsenic, antimony, lead, lithium, tin and mercury occur in anomalously high concentrations in zones of sericite-chlorite-talc-carbonate alteration surrounding known base metal mineralization. In terms of anomaly contrast, anomaly extent, and pattern homogeneity, none of these elements appear to provide a significantly better guide to mineralization than the simpler and more direct method of zinc analysis.

Trace element analysis of 'B' horizon soil and glacial till components in an area situated down-ice from known mineralized bedrock, demonstrates complete sulphide leaching and redistribution of mobile elements (Zn and Cu) by secondary near-surface weathering and soil formation processes operating in the upper 1 to 2 m (3 to 6 feet) of permeable, well-drained silty to sandy boulder till.

A survey of 1,041 complete and 1,472 partial chemical analyses of Early Precambrian tholeiitic and calc-alkaline volcanic rocks from the Abitibi, Wawa, Uchi, and Wabigoon Belts of the Superior Province of the Canadian Shield has demonstrated certain regularities in the abundance and distribution of zinc. Zinc abundances range from 3 to 200 ppm in background volcanic rocks remote from mineralization. Much of this variation is accounted for by fractional crystallization processes represented by the variables SiO_2 and total Fe. Within this range, Zn values of 120-200 ppm are related to Fe-rich tholeiitic basalts identified by levels of total FeO (FeO + 0.9 Fe_2O_3) in excess of 10.0 percent.

The average zinc contents of sampled areas in the volcanic belts vary from 80 to 95 ppm and zinc frequency distributions closely approximate a normal (bell-shaped) form.

The chemical data have been compiled and plotted to develop diagnostic charts showing zinc variability in unmineralized differentiated sequences of Early Precambrian volcanic rocks. By relating zinc abundances to SiO_2 and total iron (as FeO), components of regional background zinc variability due to the silicate fractional crystallization process can be isolated from local anomalous zinc variation attributable to mineralizing processes connected with the localization of stratabound base metal sulphide deposits of volcanogenic origin.

Geochemical Exploration of

Early Precambrian Volcanogenic Sulphide Mineralization

in

Ben Nevis Township

District of Cochrane

by

W.J. Wolfe[1]

INTRODUCTION

LOCATION AND ACCESS

Ben Nevis Township is located in the central part of the Abitibi 'greenstone' belt, 34 km (21 miles) northeast of Kirkland Lake, Ontario and 48 km (30 miles) west of Noranda, Quebec. The central part of Ben Nevis Township at Latitude 48°19′N, Longitude 79°40′W, is accessible by a gravel-surfaced forest access road extending north from Larder Lake station and linked with Highway 66 at a point approximately 1 km (0.6 miles) east of Larder Lake village. This road is presently under construction and will, in the future, provide access to the northern part of Ben Nevis Township. Verna Lake, on the western boundary of Ben Nevis Township, and Stuart Lake on the eastern boundary are accessible by float-equipped aircraft.

SCOPE AND PURPOSE OF THE GEOCHEMICAL SURVEY

The volcanic-exhalative model is now widely accepted for the origin of Precambrian stratabound base metal deposits (Derry 1973) and the recently published papers of Sangster (1972) and Hutchinson (1973) give comprehensive reviews of the distribution, internal features, mineralogy, bulk chemistry,

[1]Senior Geologist, Cominco Ltd.; formerly Chief, Geophysics/Geochemistry Section, Geological Branch. Approved for publication by K.D. Card, Chief, Geophysics/Geochemistry Section, December 20, 1976.
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alteration, host rock depositional environment and genesis of volcanogenic massive Zn-Cu-Pb-Ag-Au sulphide deposits – all explained in terms of metal-exhalative processes operating at or near the sea floor surface.

For some years now, the search for a geochemical method of distinguishing igneous rocks that have generated ore deposits from those that have not, has in general failed to establish an unambiguous connection between the concentration of metals to exploitable levels and the abundance of these metals in associated igneous rocks. A large part of the research on problems of this type was for many years concentrated on attempts to distinguish barren and productive Mesozoic felsic plutonic rocks in porphyry copper and molybdenum environments of the western United States and Canada. In the past five years, studies of primary metal dispersion by Cameron and Baragar (1971), Cameron *et al.* (1971), and Davenport and Nichol (1973) have shifted to the examination of metal distribution in Early Precambrian ultramafic and metavolcanic rocks in attempts to relate certain peculiarities of trace metal abundance to the presence or absence of Cu-Ni or Zn-Cu-Pb-Ag deposits in associated igneous rocks.

Because submarine metal-exhalative processes profoundly influenced the localization of base metal sulphide ores, and controlled the nature and extent of metal dispersion at the time of ore formation, an examination of these processes and their effects is basic to the understanding of bedrock geochemical dispersion haloes in Early Precambrian volcanic rocks of the Canadian Shield. Geochemical abnormalities directly associated with these deposits are likely to be confined to the walls of the pipes or vents through which the mineralizing solutions passed and to the stratigraphic zones in the volcanic rocks and associated sedimentary rocks where the metals were precipitated. The metal-exhalative process therefore superimposes locally anomalous geochemical patterns on regional trends of geochemical variation that are explained by normal magma differentiation.

In 1972, the Geological Branch of the Division of Mines initiated a geochemical investigation of Early Precambrian (Archean) volcanic rocks with special emphasis on the study of metal distribution in these rocks and its relationship to the existence of stratiform volcanogenic sulphide deposits. In the early stages of this work, it became apparent that from a mineral exploration standpoint, the value of the information extracted from a primary geochemical dispersion study was closely related to the type and especially the scale of geological, tectonic, and ore-forming processes operating to produce a mineral deposit, and had very little to do with overall metal abundance at the regional level. Indeed, the data gathered to date suggest that unless geochemical rock sampling of Early Precambrian 'greenstone' belts is carried out in detail consistent with the scale of mineralized pipes and stratigraphic zones, the results will seldom be of value in making mineral exploration decisions.

Ben Nevis and the adjacent Townships of Clifford and Pontiac are underlain by a calc-alkaline suite of metavolcanics which form the western part of the Blake River Group and are grossly equivalent in chemistry and age to the calc-alkaline volcanic piles which contain important massive Cu-Zn-Ag deposits in the Rouyn-Noranda area of Quebec. This fact, coupled with the known existence of sub-economic occurrences of Cu-Zn-Ag-Au sulphide mineralization in central Ben Nevis Township, led to the selection of the Ben Nevis area for detailed geochemical investigation.

To arrive at more general conclusions concerning levels of base metal abundance in Early Precambrian metavolcanic belts and to achieve wider-based estimates of background metal concentrations, geochemical data from other widespread localities within the Superior Province of the Canadian Shield have been incorporated in this report.

In addition to the primary investigation of base metal dispersion in volcanic rocks of the Ben Nevis area, a subsidiary study of secondary metal dispersion in glacial tills was undertaken at the same time.

ACKNOWLEDGMENTS

The writer was assisted in the field collection, subsampling and preparation of geochemical samples by P. Coad, B. Hatchkowski, M.J. Shulist and J. Fitzpatrick. The geochemical study of Early Precambrian volcanic rocks in the Ben Nevis area was only possible because of the interest and co-operation of L.S. Jensen of the geological staff of the Division of Mines, Ontario Ministry of Natural Resources, whose geological mapping of the area formed the groundwork for the geochemical sampling and interpretation. I also wish to extend acknowledgment to L.S. Jensen for significantly enhancing the completeness of the Ben Nevis study by making his samples available for chemical analysis. R.B. Barlow kindly permitted the writer to use certain chemical data from his unpublished M.Sc. thesis.

All chemical analyses were performed by the staff of the Mineral Research Branch of the Division of Mines, under the direction of A.E. Pitts. S.R. Parmar made a substantial contribution in the compilation and plotting of chemical data.

GEOLOGY

Precambrian Geology

The geology of Ben Nevis Township and of Clifford Township, immediately west of Ben Nevis, has been previously described by Jensen (1975) in a report which included a 1 inch to ½ mile (1:31,680) scale geological map. The general geological summary that follows is derived from Jensen's work and is intended only to provide a background for presentation of the geochemical data. Jensen's report (Geoscience Report 132) should be consulted for additional detail concerning the geology and mineral deposits of the area.

With the exception of a single northwest-striking diabase dike of possible Middle to Late Precambrian (Keweenawan?) age, all of the bedrock in the map-area is Early Precambrian (Archean). The sequence of geological events is summarized in the Table of Lithologic Units, Table 1. Intermediate and felsic volcanic rocks predominate within a layered Early Precambrian volcanic sequence of flow and pyroclastic units flanking a massive to porphyritic, sub-volcanic gra-

nodiorite-quartz diorite stock located in southeastern Clifford Township. The volcanic assemblage contains minor inter-flow sedimentary units. At the stratigraphic base of the volcanic sequence, massive and pillowed basalt flows form a 240 to 370 m (800 to 1,200 feet) thick unit on the northern and southern limbs of an eastward-trending domal anticline, the axis of which is intruded by granitic rocks of the Clifford Stock (see Figure 2).

Intermediate volcanic rocks of andesite-dacite composition consist of massive and pillowed flows, flow breccia, and pyroclastic units of agglomerate, tuff-breccia, lapilli-tuff and tuff. Many of the intermediate pyroclastic units contain felsic volcanic rock fragments in a predominantly intermediate matrix. The felsic volcanic rocks include massive dacite-rhyolite, rhyolite feldspar porphyry and rhyolite quartz porphyry plugs, and pyroclastic units consisting of flow-breccia, tuff-breccia, lapilli-tuff, and crystal tuff. The layered felsic pyroclastic rocks form two stratigraphically distinct (lower and upper) units whose relative stratigraphic positions are distinguished by pillow top determinations in intervening intermediate volcanic lithologies (Figure 3). The lower rhyolite pyroclastic unit occurs on both limbs of the syncline which flanks the north, south, and east sides of the east-plunging domal anticline. On the inner limb of the syncline, the lower rhyolite dips steeply outward from the domal axis and ranges in thickness from 60 to 300 m (200 to 1,000 feet). On the north limb of the syncline where the lower rhyolite dips 50° to 60°S, its thickness ranges from 120 to 300 m (400 to 1,000 feet). The upper rhyolite pyroclastic unit ranges from 120 to 460 m (400 to 1,500 feet) in thickness and occurs close to the synclinal axis which surrounds the domal structure.

The Ben Nevis Township volcanic rocks in general display a calc-alkaline chemical affinity consistent with low total iron content (less than 10.0 percent total Fe expressed as FeO) in the basalts and andesites. In a group of 343 randomly distributed samples of volcanic rocks from the Ben Nevis map-area the average SiO_2 content was 58.0 percent and the average iron content (total as FeO) was 6.56 percent. The partial analyses could be grouped as follows:

	SiO_2 (%)	Frequency	Total Fe as FeO (%)	Frequency
Basalt	<54.0	121	>8.0	79
Andesite	54.0–62.0	142	6.0–8.0	152
Dacite	62.0–70.0	44	3.0–6.0	79
Rhyolite	>70.0	36	<3.0	33

A group of 30 complete whole rock analyses of volcanic rocks from the Clifford-Ben Nevis Townships area are listed by Jensen (1975, p.29-30), and were chemically classified using: the standard AFM diagram based on the cation percentages of Na_2O, K_2O, FeO, Fe_2O_3 and MgO; the percent Al_2O_3 versus normative plagioclase plot of Irvine and Baragar (1971); and the Jensen cation plot relating the ternary cation percentages of Al_2O_3, FeO + Fe_2O_3 + TiO_2, and MgO (Jensen 1976). The classification of these samples illustrates the overall calc-alkaline nature of the Blake River Group volcanic rocks as represented in the Clifford-Ben Nevis Townships map-area (Jensen 1975, p.32-33).

The layered volcanic assemblage was intruded by sills, dikes and stocks of gabbro, quartz gabbro, hornblende gabbro, diorite, quartz diorite and granodiorite. The range in composition of the intrusive rocks is similar to that of the vol-

Table 1 TABLE OF LITHOLOGIC UNITS FOR THE CLIFFORD-BEN NEVIS TOWNSHIPS AREA (from Jensen 1975).

CENOZOIC

QUATERNARY

RECENT

Peat, alluvium

PLEISTOCENE

Gravel, sand, till and clay

Unconformity

PRECAMBRIAN

MIDDLE TO LATE PRECAMBRIAN (PROTEROZOIC)

MAFIC INTRUSIVE ROCKS

Olivine diabase, quartz diabase.

Intrusive Contact

EARLY PRECAMBRIAN (ARCHEAN)

FELSIC INTRUSIVE ROCKS

Granodiorite, quartz diorite, diorite, syenite, feldspar porphyry, and quartz-feldspar porphyry.

Intrusive Contact

MAFIC TO INTERMEDIATE INTRUSIVE ROCKS

Gabbro, quartz gabbro, hornblende gabbro and diorite.

Intrusive Contact

VOLCANIC ROCKS

FELSIC VOLCANIC ROCKS

Rhyodacite and rhyolite: Massive, flow-breccia, tuff-breccia, tuff and lapilli-tuff.

INTERMEDIATE VOLCANIC ROCKS

Andesite and dacite: Massive, pillowed, flow-breccia, tuff, argillite.

MAFIC VOLCANIC ROCKS

Basalt: Massive, pillowed, flow-breccia, tuff-breccia.

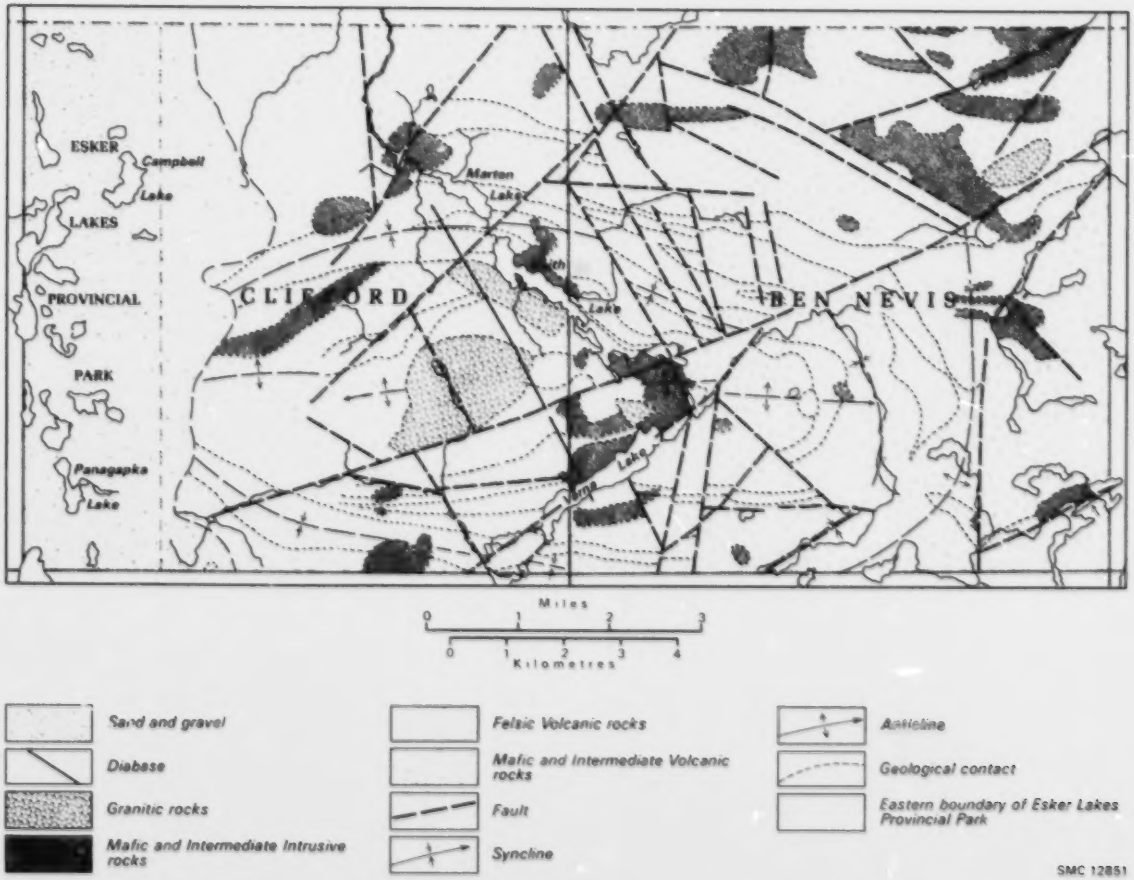


Figure 2–Geological sketch map of Clifford and Ben Nevis Townships (from Jensen 1975).

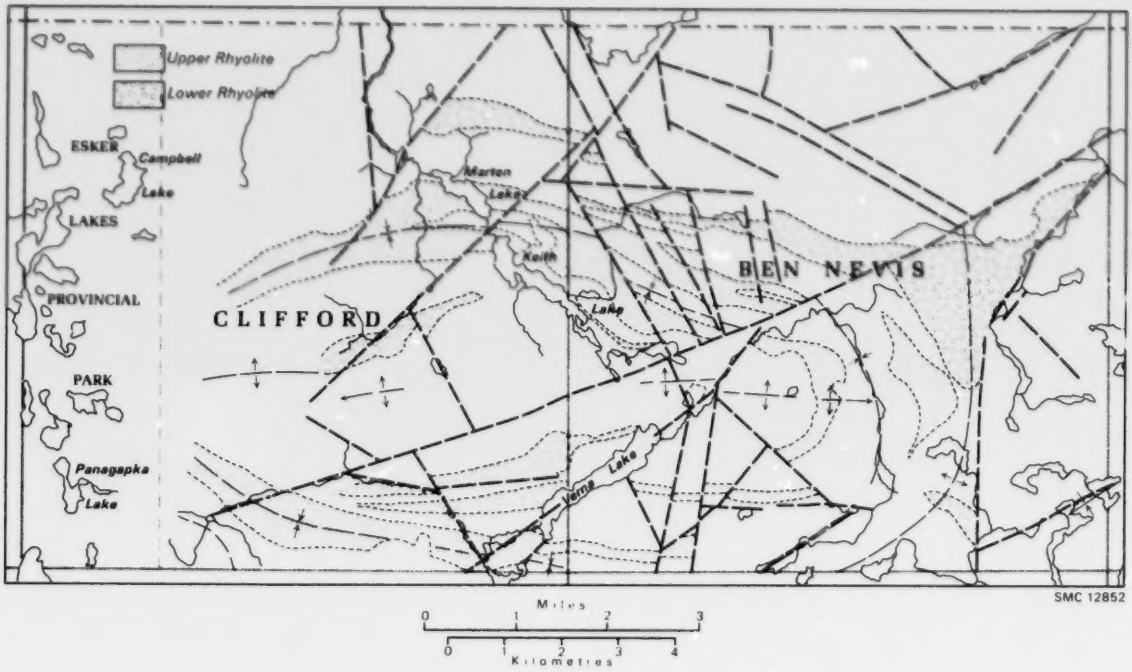


Figure 3–Distribution of upper and lower layered felsic volcanic units in Clifford and Ben Nevis Townships (from Jensen 1975).

canic rocks. The granodiorite-quartz diorite stock in eastern Clifford Township is approximately 1800 m (6,000 feet) in diameter and cuts all rock types of the map-area excepting a younger northwest-trending olivine diabase dike. The contact between the granodiorite intrusion and surrounding volcanic strata is sharp and dips outward from the centre at 40 to 60 degrees. Low-grade regional zeolite-facies metamorphism has been upgraded to albite-epidote hornfels rank within a 460 m (1,500 feet) wide aureole around the granodiorite stock.

In western Ben Nevis and eastern Clifford Townships, the volcanic strata are folded concentrically in an open, east-trending anticlinal dome that is flanked to the north, east and south by a complimentary syncline. A second anticline with an arcuate, north- to northeast-trending, double plunging axis is situated to the east of the syncline and it is along the hinge line of this structure that much of the base metal exploration has so far occurred. The volcanic strata are displaced by early local faults and late regional faults. The early faults are synvolcanic radial and 'circular' tensional fractures related to the Clifford subvolcanic granodiorite stock. Local radial faults in the west-central part of the map-area were intruded by granodiorite and feldspar porphyritic granodiorite dikes and extend outward up to 1.6 km (1 mile) from the boundaries of the Clifford Stock. Short, block faults that are subparallel to the margins of the Clifford stock may represent volcanic collapse structures related to a central eruptive vent located in east-central Clifford Township at a site now occupied by the unroofed subvolcanic intrusion. These early short-strike local faults connected with volcanic events are truncated and offset by major northeast striking late faults of regional strike extent.

Pleistocene Geology, Topography, and Physical Features

The Ben Nevis Township area forms part of an extensive east-west trending upland region of thinly till-covered bedrock that identifies the Hudson Bay–St. Lawrence River watershed divide. This separates areas of flat lowland topography covered by lacustrine sediments of glacial Lake Barlow to the south and glacial Lake Ojibway to the north. The watershed divide between the north-flowing Hudson Bay drainage through the Magusi River system and the south flowing St. Lawrence Basin drainage through the Misema River system crosses the central part of the map-area. Extensive outcrop areas occur in Ben Nevis and eastern Clifford Townships where local relief in areas around Verna Lake and Pushkin Lake ranges from 150 to 180 m (500 to 600 feet). More generally, the local relief is from 9 to 15 m (30 to 50 feet). The area is generally well drained although stream and river systems are locally impeded by small swamps and beaver ponds.

Eskers, drumlinoid features, streamlined topographic features, bedrock striations and fluting indicate that the last sheet of continental ice advanced across the Ben Nevis area in a S20E direction. The Canagau Mines Limited deposit is located at the up-ice end of a linear southeast-trending ridge (see Figure 19) that is subparallel to the glacial flow direction over a distance of about 1500 m (4,900 feet). The till sheet covering the crest of this ridge seldom exceeds a thickness of 3 m (10 feet). Commonly it is much less. A general thickening of till deposits to

the east and west of this ridge suggests that the present topography is a subdued reflection of the pre-Quaternary bedrock surface. Well-differentiated podzolic soils are developed on the freely drained till sheet that covers most of the upland area. Forest cover consists mainly of spruce, jack pine, poplar, birch and balsam.

Economic Geology and Mineral Exploration

Prospecting in Ben Nevis and Clifford Townships began in the late 1920s following the discovery of gold at Larder Lake and gold and base metals at Noranda, Quebec. In 1926, P.J. Roche and E.O. Ehrhart discovered gold, galena, sphalerite and chalcopyrite west of Ranger Lake and other discoveries were made by Ehrhart and J. Martin in the area north and northwest of Verna Lake. From 1927 to 1929 the Interprovincial Exploration Company Limited sunk several trenches, pits and two shafts on the Roche discovery in east-central Ben Nevis Township. The shafts consist of one inclined prospect shaft, 12 m (40 feet) deep and one vertical shaft 105.5 m (346 feet) deep with crosscuts extending south from the 38.1, 68.6 and 99.0 m (125, 225 and 325-foot) levels for distances of 10, 146, and 128 m (34, 480 and 420 feet) respectively (Jensen 1975, p.37-38). In 1936, Canagau Mines Limited acquired the Interprovincial property and the Ehrhart-Costello group of claims to the south. At various periods during the next 25 years, mainly in 1937, 1946, 1960 and 1962, geological surveys, ground magnetic and electromagnetic surveys, diamond drilling, surface stripping and trenching were carried out on and near the original discoveries. No significant metal reserves were discovered and no mineral production resulted from any of these exploration programs.

The area experienced a renewal of base metal exploration interest after the 1971 release of preliminary geological maps P.629 (Pontiac Township), P.692 (Clifford Township) and P.693 (Ben Nevis Township) at a scale of 1 inch to ¼ mile by L.S. Jensen. Airborne electromagnetic surveys were flown over a large block of claims staked by Amax Exploration, Incorporated in east-central Ben Nevis Township and west-central Pontiac Township and over a smaller claim group staked by Cominco Limited near Captain Lake in south-central Ben Nevis Township. Amax Exploration, Incorporated subsequently optioned the group of 13 patented claims held by Canagau Mines Limited and conducted induced polarization and rock geochemical surveys with follow-up diamond drilling in the area west and northwest of Ranger Lake.

The deposits in east-central Ben Nevis Township northwest of Ranger Lake are closely associated with strongly foliated, carbonatized and sericitized rhyolite tuff, tuff-breccia and lapilli-tuff of the lower rhyolite pyroclastic unit (Figure 3). The Canagua mineralization is localized near the hinge line of a south plunging anticlinal structure, the core of which is occupied by the structurally thickened lower rhyolite pyroclastic unit. Sphalerite, galena, chalcopyrite, pyrite, pyrrhotite, silver and gold occur in deposits described as veins or massive replacements in shear zones in altered rhyolite tuff, or as disseminated minerals in adjacent tuff. The main vein or shaft vein is exposed at surface in an outcrop of rhyolite tuff and can be traced over a length of 24 m (80 feet) with widths of 15 to 45 cm (6 to 18 inches). Surface and underground work suggests that the vein strikes east for 120 m (400 feet) and extends to a vertical depth of 99 m (325 feet) al-

though geological plans and sections given by Jensen (1975, p.38) indicate that the mineralization may more realistically be represented by a vein stockwork rather than a single vein. Extensive sericite, chlorite, talc and carbonate alteration is developed in the mineralized rhyolite tuff near the Canagua shafts. South of the shafts, the sheared tuffaceous volcanic rocks along the axial trace of the major south-trending fold structure contain widespread disseminated sulphide minerals. The volcanic units flanking the central rhyolite core rocks to the southwest are highly chloritized and contain vesicle fillings of chalcopyrite and chlorite. The Canagau deposit has more similarity with stockwork stringer mineralization in alteration pipes which underlie exhalative massive Cu-Zn-Pb-Ag-Au sulphide deposits than with vein-replacement mineralization.

GEOCHEMISTRY

Sampling and Chemical Analysis of Rocks, Soils, and Till

ROCKS

During 1972, 335 samples of bedrock were collected in southern Ben Nevis Township for the purpose of determining patterns of metal variation in relation to mineralized volcanic strata. Representative volcanic bedrock was sampled at more or less evenly spaced but randomly distributed sites located by pace and compass traverses tied to survey grids or recognizable features on 1 inch to ¼ mile (1:15,840) scale air photographs. Sample density was increased near known occurrences of base metal sulphide minerals north of Verna Lake and west of Ranger Lake. This collection of 335 samples was augmented by 653 specimens collected by L.S. Jensen and D.S. Hunt during a 1969 program of 1 inch to ¼ mile (1:15,840) scale geological mapping in Clifford and Ben Nevis Townships. The combined groups of samples therefore represented 988 outcrop locations in a 90 km^2 (35 square miles) area covering the southern two-thirds of Ben Nevis Township and the extreme southeastern part of Clifford Township. All samples were initially analyzed for Zn, Cu, Ni, Pb, Co and Mn. A selected group of 359 samples was later analyzed for Hg, SiO_2 and total Fe.

The rock specimens were successively passed through a jaw crusher and a cone crusher set to deliver material of about 10 mesh size. After mixing by riffling on paper sheets, a sample split was taken for grinding to -200 mesh size in a ceramic ball pulverizer. Samples of rock powder weighing 300 mg were treated with hot HNO_3-HCl leach, and the resulting solutions were diluted to 15 ml and aspirated for the determination of zinc, copper, nickel, lead, cobalt and manganese by atomic absorption spectrophotometry. Based on a sample-weight/solution-volume ratio of 0.300 g/15 ml, the sensitivities (e.g. concentrations giving 1 percent absorption) achievable by the routine instrumental techniques used were 1 ppm Zn, 3 ppm Cu, Mn, and Co, and 4 ppm Ni in the solid sample. Duplicate analyses of control sample splits for Zn, Cu and Ni demonstrated combined analytical precision and sample homogeneity of ± 15 percent or better at the 95 percent confidence level for Cu and Zn concentrations above the 10 ppm and Ni concentrations above 25 ppm.

To test the metal extraction efficiency of the hot HNO_3-HCl leaching technique, a group of 306 samples of volcanic rocks were selected to cover the 5 to 400 ppm range of Cu, Ni and Zn concentrations and these samples were re-analyzed using a total decomposition HF-HCl-HNO_3 leach. The two methods of sample decomposition are compared in Figures 4, 5 and 6. Figure 5 illustrates the well known chalcophile nature of Cu and indicates that within the limitations of analytical error (i.e. precision), 95 to 100 percent of the total Cu present in these samples exists in the form of hot aqua regia soluble sulphide minerals. In comparison, Figures 4 and 6 show that substantial proportions of the total Zn and Ni present are present in silicate minerals which are insoluble in aqua regia (HNO_3-HCl) solutions. Addition of hydrofluoric acid to the leach does not significantly change the amount of Cu brought into solution but does significantly increase the amounts of Ni and Zn by releasing Ni and Zn bound in the lattices of primary olivine, pyroxene and amphibole minerals. These data confirm the generally known facts that Cu in unmineralized volcanic rocks is distributed almost solely in sulphide phases, while Ni is distributed in significant proportions in the octahedral Fe-Mg sites of silicate phases. What is not so widely appreciated, is that Zn is much less chalcophile in behaviour than Cu and that zinc sulphide phases are extremely rare in normal unmineralized volcanics. Zinc is closely tied to Fe^{+2} sites in silicate and oxide phases and in this respect, its behaviour is more similar to nickel.

A separate sample split was used for the determination of mercury, and this material was hand ground to prevent Hg loss due to heating. A comparison of Hg analyses obtained from crushed material prepared (1) by controlled temperature hand grinding, and (2) by pulverization in a mechanical ceramic ball mill, is given in Table 2. It is apparent that significant Hg losses can occur when the sample material is subject to frictional heat produced by a mechanical pulverizer.

A modification of the cold vapour atomic absorption method was used for the determination of mercury in rock samples. The method is summarized as follows. The sample is decomposed in HNO_3-HCl (aqua regia) in the presence of potassium permanganate. Decomposition of sulphide minerals in aqua regia leads to loss of SO_2 at this stage, and the presence of a strong oxidizing agent ($KMnO_4$) prevents the formation of Hg (0) and loss of Hg in the gaseous state. After the sample is digested, a reducing agent (stannous chloride) is added prior to bubbling the sample gas through a closed system tube to a cell in the light path of an atomic absorption spectrometer. Absorption of the 2537 angstrom Hg emission line radiation by Hg (0) atoms is then measured against standard Hg solutions.

Three hundred and six selected samples were analyzed for SiO_2 and total Fe by X-ray fluorescence techniques in order to relate trace metal variations in the Ben Nevis Township rocks to variations in bulk rock chemistry as represented by these two major oxides.

SOILS AND GLACIAL TILL

In an area measuring 2.5 km (1.6 miles) east-west by 1.5 km (0.9 miles) north-south and extending southward from the Canagau Mines Limited shafts, soils and glacial till were sampled at 50 locations to outline patterns of metal dis-

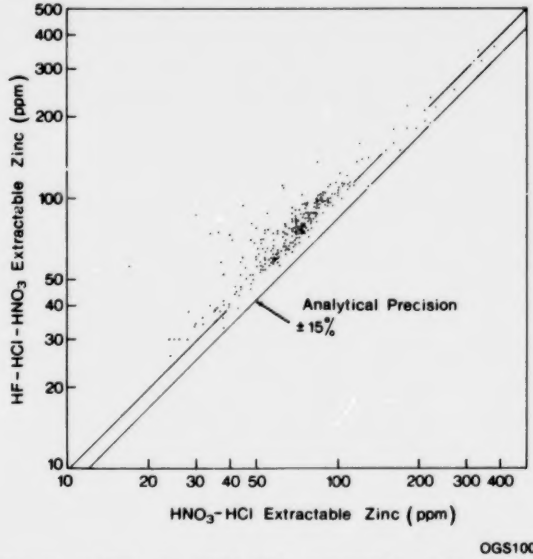


Figure 4–Plot of HNO_3-HCl extractable zinc versus HF-HCl-HNO_3 extractable zinc in Ben Nevis Township volcanic rocks.

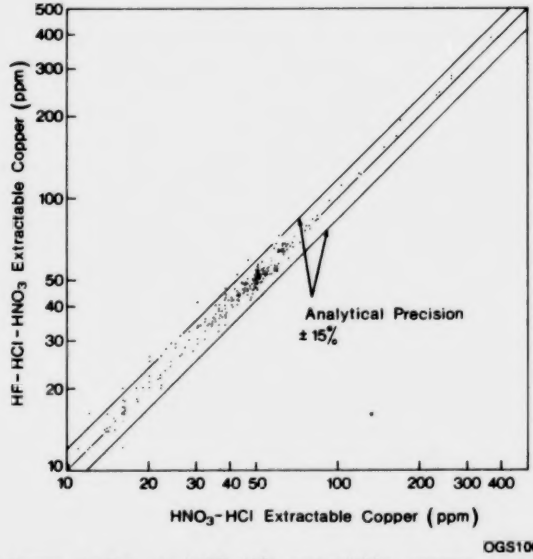


Figure 5–Plot of HNO_3-HCl extractable copper versus HF-HCl-HNO_3 extractable copper in Ben Nevis Township volcanic rocks.

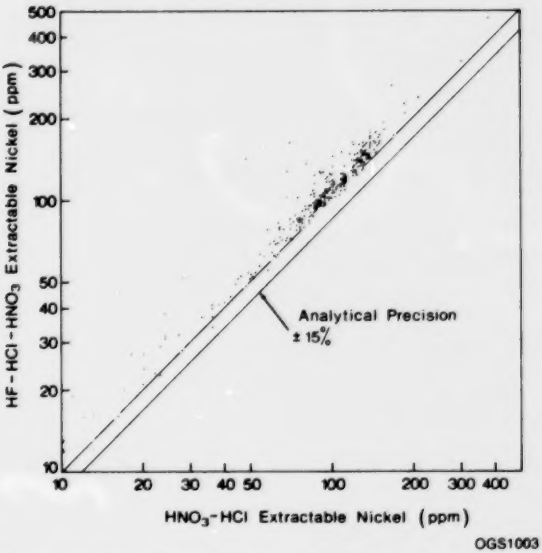


Figure 6–Plot of HNO_3-HCl extractable nickel versus HF-HCl-HNO_3 extractable nickel in Ben Nevis Township volcanic rocks.

persion in glacial deposits situated "down-ice" from the known base metal sulphide mineralization. At each site samples were collected from the upper "B" soil horizon and from the parent glacial till scraped from the walls of 75-100 cm (30-40 inches) deep pits located along traverse lines oriented normal to the local ice-flow direction (S20E). Till samples weighing approximately 3.5 kg (7.7 pounds) were oven-dried at 80°C and passed through 80- and 250-mesh screens. The minus 80-mesh fraction of "B" horizon soils and the minus 250-mesh fraction of glacial tills were leached with hot HNO_3-HCl and analyzed for copper, zinc, lead, nickel, cobalt and manganese by atomic absorption spectroscopy methods. Heavy minerals were separated in tetrabromethane (specific gravity 2.96) from till sample material in the minus 80-mesh, plus 250-mesh particle-size range. The heavy mineral concentrates were examined microscopically and were analyzed for hot HNO_3-HCl leachable copper, zinc, lead, nickel, cobalt, and manganese.

DATA PROCESSING

Sample identification and chemical data for each of the bedrock samples collected in the Ben Nevis Township area were transferred to 80-column computer cards for electronic data processing. The positions and sample identifications were digitized from 1 inch to ¼ mile (1:15,840) base maps to assign geographic X and Y co-ordinates to the samples. These results were later merged on magnetic

TABLE 2 COMPARISON IN MINERALIZED AND BARREN ROCK SUITES OF MERCURY CONTENT OF CRUSHED ROCK POWDERS PREPARED (1) BY HAND MORTAR AND PESTLE GRINDING AND (2) BY GRINDING IN A MECHANICAL CERAMIC BALL MILL.

Sample	Zinc %	Zinc ppm	1 Mercury (ppb) Hand Ground	2 Mercury (ppb) Ball Mill
SULPHIDE MINERALIZED ROCKS (from Canagau Mines Ltd. deposit, Ben Nevis Tp.)				
1	8.85		215	280
2	0.15		65	40
3	0.64		120	60
4	5.55		280	210
5	15.30		570	500
6	4.38		210	180
7	0.08		50	40
UNMINERALIZED ROCKS (Ben Nevis Tp.)				
8		72	50	40
9		80	70	40
10		70	60	30
11		75	30	30
12		78	70	30
13		68	120	40
14		84	70	30
15		72	180	30

Analyses by Mineral Research Branch, using modified cold vapour atomic absorption method (see text).

tape to produce a complete record of location and chemical data. Computer plotted contours of regional copper, zinc, and nickel variations within the volcanic rocks were generated from orthogonal grids of regularly spaced data points derived from the original irregularly spaced data points by a moving average technique. Extremely high zinc and copper values were truncated by the contouring program at 500 parts per million to avoid undue bias in averaging caused by single sample spikes in the data. The Ontario Government UNIVAC 1106 computer was programmed to:

(1) Compute arithmetic means, geometric means, standard deviations, ranges and medians for each of the analyzed trace metals.

(2) Construct histograms and cumulative frequency curves for each element using both raw untransformed and logarithmically transformed data.

(3) Compute correlation matrices for untransformed and logarithmically transformed trace element and major oxide data.

(4) Plot chemical variation diagrams using SiO_2 and FeO (total Fe as FeO) as independent variables and Zn, Ni and Cu as dependent variables.

Trace Metal Distribution in Volcanic Rocks

ZINC

The aqua regia soluble zinc content of sample volcanic rocks in the Ben Nevis Township area ranges from 8 ppm to 11,550 ppm. To obtain an unbiased estimate of the average Zn abundance in unmineralized background volcanic rocks, anomalously high zinc values attributable to the existence of sphalerite mineralization were discarded prior to the calculation of statistical parameters. Zinc abundance ranges from 8 ppm to 150 ppm in normal volcanic rocks remote from mineralization and much of this variation is accounted for by fractional crystallization processes which produce a trend of Zn depletion with increasing SiO_2 and decreasing total Fe. The average Zn content of unmineralized volcanic rocks is 70 ppm and the curve of Zn frequency distribution closely approximates a normal, bell-shaped form (see Figure 8 on Chart A, back pocket). The upper tail of the normal distribution curve is truncated at about 150 ppm and zinc concentrations above this limit presumably reflect a secondary mineralizing process superimposed on a primary background pattern.

Contours of Zn concentration are shown in Figure 9 (Chart A, back pocket) at intervals of 10 ppm between 50 and 100 ppm and at higher levels of 125, 150, 200 and 250 ppm. This contoured map showing regional average Zn variations can be compared with Figure 7 (Chart A) showing levels of zinc concentration in individual samples.

Figures 7 and 9 outline a broad zone of anomalous zinc in layered felsic pyroclastic rocks of the lower rhyolite unit situated along the arcuate, south-trending axis of the doubly plunging anticline in east-central Ben Nevis Township. The Zn anomalies occur within a zone which cross-cuts stratigraphic boundaries and extends from the area of the Canagau Mines Limited shafts southward to the vicinity of Captain Lake. A large number of the abnormally high Zn values cluster within the southern part of the unit of rhyolite tuff, tuff breccia and lapilli tuff that underlies much of the Canagau Mines Limited property. In comparison, the stratigraphically higher parts of the volcanic pile (i.e. the upper rhyolite pyroclastic unit) contain low concentrations of Zn that are typical of unmineralized rhyolitic rocks.

A second cluster of zinc anomalies is related to rhyolite quartz-feldspar porphyry and associated rhyolite breccia in the area between the northeastern end of Verna Lake and the southeastern end of Keith Lake. In the northwestern part of the map-area, discontinuities in the Zn contour pattern reflect the existence of north- to northwest-trending transverse faults that cross-cut the volcanic stratigraphy.

COPPER

The aqua regia soluble copper content of sample volcanic rocks in the Ben Nevis Township area ranges from 3 ppm to 29,500 ppm. To obtain an unbiased estimate of the average Cu abundance in unmineralized volcanic rocks, highly

anomalous Cu values exceeding 250 ppm were discarded prior to the calculation of statistical parameters shown in Figure 11 (Chart A, back pocket). Copper abundance ranges from 3 ppm to 150 ppm in normal volcanic rocks remote from mineralization and much of this variation is accounted for by fractional crystallization processes which produce a trend of Cu depletion with increasing SiO_2 and decreasing total Fe. The average Cu content of unmineralized volcanic rocks is 45 ppm. Copper concentrations above 150 ppm presumably reflect the existence of chalcopyrite related to a mineralizing process. It should be recognized however, that because background and threshold limits vary systematically according to the bulk composition of the volcanic rocks, Cu values in the range of 50 to 150 ppm represent normal levels in basalts and andesites but may be categorized as anomalous in rocks of dacite-rhyolite composition. The plot of Cu concentration frequency distribution shows a distinct bimodal form with peaks located in the 0-10 and 40-50 ppm class intervals (see Figure 11). The secondary histogram peak in the 0-10 ppm class is almost entirely explained by samples collected from unmineralized rhyolite units.

Contours of Cu concentration are shown in Figure 12 (Chart A, back pocket) at intervals of 10 ppm between 30 and 100 ppm and at higher levels of 125 and 150 ppm. This contoured map showing regional average Cu variations can be compared with Figure 10 (Chart A, back pocket) showing levels of Cu concentration in individual samples.

Figures 10 and 12 outline a broad zone of anomalous copper associated with the unit of rhyolite tuff, tuff-breccia and lapilli tuff that contains known base metal mineralization on the Canagau Mines Limited property. The zone of Cu anomalies cross-cuts stratigraphic boundaries and extends southwestward from the area of the Canagau shafts for a distance of 1800 m (6,000 feet). The contoured regional Cu anomaly (Figure 12) coincides approximately with the zinc anomaly (Figure 9) but detailed examination of the data indicates that the highest Cu/Zn ratios occur in the highly chloritized volcanic units that flank the central rhyolitic pyroclastic axial core immediately southwest of the Canagau Mines Limited property. North of the Canagau shafts and elsewhere within the map-area, the layered felsic volcanic units contain low concentrations of copper (less than 30 ppm) that are typical of unmineralized rhyolitic rocks.

Copper anomalies related to rhyolite quartz-feldspar porphyry and associated rhyolite breccia are clustered in the area northwest of Verna Lake and south of Keith Lake. The strong regional Cu anomaly centred between the Clifford-Ben Nevis Townships boundary and the eastern end of the Clifford granodiorite stock is attributable to three samples of massive to brecciated flow rhyolite which contained Cu in amounts exceeding the 500 ppm cut-off imposed by the contouring program.

NICKEL

The aqua regia soluble nickel content of sampled volcanic rocks in the Ben Nevis Township area ranges from 3 ppm to 382 ppm and this variation is essentially controlled by fractional crystallization processes which produce a trend of Ni depletion with increasing SiO_2 and decreasing total Fe. The average Ni content of igneous rocks in the map-area is 80 ppm. The plot of Ni frequency

distribution shows a distinct bimodal form with peaks located in the 0-10 ppm and 80-90 ppm class intervals (see Figure 14, Chart A, back pocket). The high frequency of Ni values in the 0-10 ppm class interval is almost entirely explained by samples from rhyolitic volcanic units. Regional average Ni variation is contoured at intervals of 10 ppm in Figure 15 and can be compared with Figure 13 showing levels of Ni concentration in individual samples.

No nickel sulphide mineralization is known in the map-area and Ni is not a suitable indicator for the Zn-Cu-Pb-Ag-Au deposits that are associated with the calc-alkaline volcanic environment in Clifford and Ben Nevis Townships. Nevertheless, Ni variation is sensitive to changes in the bulk chemistry of the differentiated igneous rocks and is, therefore, useful in identifying major lithological units. Northeast of Verna Lake, the basaltic and andesitic lavas and related gabbros that occupy the axial part of the major east-plunging anticlinal structure are identified with a nickel high outlined by the 100 ppm Ni contour. Similar Ni highs coincide with thick sequences of mafic volcanics along the northern and southern edges of the map-area. Volcanic units of dacite-rhyolite composition located northwest of Ranger Lake, west of Wicklan Lake, east and northeast of Keith Lake, and in south-central Ben Nevis Township contain low Ni abundances – generally less than 20 ppm. The moving average method tends to remove steep gradients in the nickel contour pattern so that otherwise well defined geochemical boundaries lack clear definition in the resulting contour map. Nevertheless, major structural and lithologic trends are still discernible in Figure 15.

The only important inconsistency between the mapped geology and the geochemical results relates to the felsic volcanic unit centred 1.6 km (1 mile) west of Ranger Lake and 0.8 km (½ mile) northwest of Captain Lake. Altered tuffaceous volcanic rocks in this area are bleached and highly chloritized. The high Ni content of these rocks (in combination with low SiO_2 and high total Fe) is consistent with the author's conclusion that a large part of this mapped felsic volcanic unit is in fact basaltic or andesitic in composition.

MERCURY

The mercury content of sampled volcanic rocks in the Ben Nevis Township area ranges from less than 20 ppb, the lower detection limit of the analytical method, to greater than 200 ppb in samples containing significant sulphide mineralization (see Table 2). The mercury background in normal unmineralized volcanic rocks lies in the 30-40 ppb range and the threshold level marking the division between background and anomalous values is placed at 100 ppb.

Figure 16 shows the distribution of anomalous mercury in rock samples collected from a 17 km^2 (6.6 square miles) area in east-central Ben Nevis Township. Superposition of contoured average zinc concentration (from Figure 9) on the Hg data in Figure 16 shows that almost all of the anomalous Hg values fall within an area already defined as being anomalous on the basis of Zn determinations. Mercury concentrations in sulphide mineralized samples collected near the Canagau shaft mineralization are listed in Table 2. It is apparent that in this case at least, mercury geochemistry does not provide a significantly better guide to mineralization than the simpler and more direct method of zinc analysis.

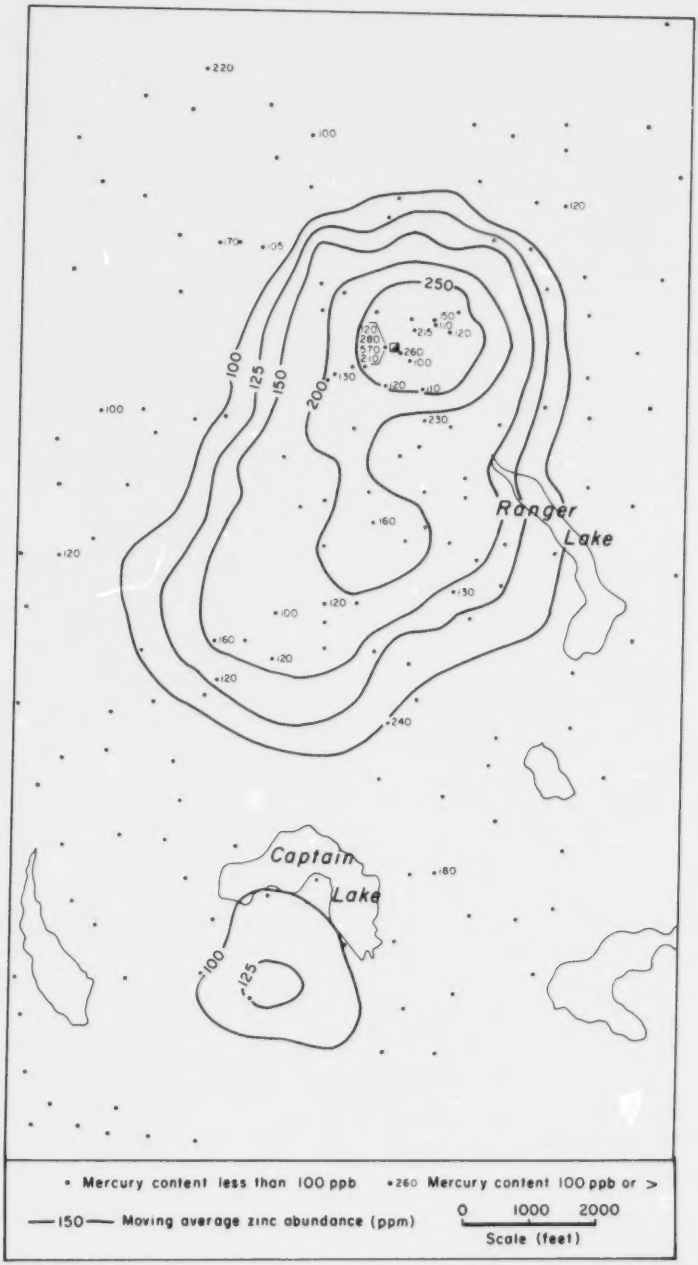


Figure 16–Distribution of anomalous mercury concentrations in relation to averaged zinc content; east-central Ben Nevis Township.

OTHER TRACE ELEMENTS

The aqua regia soluble manganese content of sample volcanic rocks in the Ben Nevis Township area ranges from 34 ppm to 5,000 ppm and this variability is essentially a reflection of fractional crystallization processes which produce systematic Mn depletion with increasing SiO_2 and decreasing total Fe in igneous rocks. The average manganese content of rocks in the map-area is 708 ppm and 98.4 percent of the analyses fall within the 100 to 1,500 ppm range, producing a symmetrical bell-shaped distribution curve with a maximum in the 600-700 ppm class interval (see Figure 17). Manganese is mainly substituting for iron in silicate and oxide minerals and, like nickel, is most useful as a trace element indicator of changes in the bulk chemistry of the differentiated rocks. It is not a useful indicator of base metal sulphide mineralization.

The aqua regia cobalt content of the Ben Nevis Township volcanic rocks ranges from less than 4 ppm (the lower analytical detection limit) to 55 ppm. The average Co abundance in 988 analyzed rocks is 21 ppm and 99.2 percent of the analyses fall within the 0 to 45 ppm range. The Co frequency histogram (Figure 18) shows a maximum in the 20-25 ppm class interval with a secondary peak in the 0-5 ppm class. Cobalt enters Ni-Mn-Fe sites in silicate and oxide minerals but because of its lower variance in concentration, it is much less sensitive than Ni and Mn to changes in bulk rock chemistry. Cobalt shows no enrichment in or near base metal sulphide mineralization.

The aqua regia extractable lead content of normal unmineralized volcanics is consistently less than 15 ppm (the lower limit of analytical detection). Only 3.9 percent of the 988 samples analyzed in this study contained Pb in amounts greater than 15 ppm. Nevertheless, the small group of samples containing Pb in the range of 100 to 5,600 ppm could be closely related to observable or inferred base metal sulphide mineralization, mainly in the vicinity of the Canagau Mines Limited deposits. Lead anomalies are invariably associated with zinc anomalies of 300 ppm or greater.

A suite of 17 samples of volcanic rocks from central Ben Nevis Township was analysed for all major oxide constituents and a group of 20 trace elements. The analyses listed in Table 3 are a fair representation of the spectrum of volcanic rock compositions encountered in this study. Samples 1 to 14 in Table 3 are normal unmineralized rhyolites, calc-alkaline andesites and tholeiitic basalts. Samples 15 to 17 are strongly sericite-chlorite and/or carbonate-talc altered tuffaceous rhyolites collected in the vicinity of the Canagau shafts and trenches. The latter group of three analyses shows significant SiO_2 depletion, MgO, FeO and H_2O enrichment, and CO_2 enrichment in samples 16 and 17.

The trace element data given in Table 3 show that samples 15 to 17 collected near known mineralization, are significantly enriched in As, Li, Pb, Sb, Zn and Sn in relation to unmineralized samples 1 to 14.

Metal Dispersion in Soils and Quaternary Deposits

Figures 19 to 21 summarize the zinc concentrations in soil and till fractions collected from the Ben Nevis Township study area. All three figures show a pattern of Zn dispersal presumably caused by glacial erosion of zinc-rich bedrock

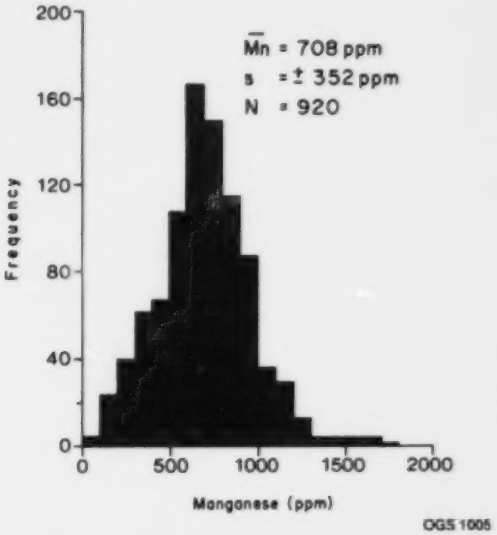


Figure 17–Histogram of manganese abundance in volcanic rocks of the Clifford-Ben Nevis Townships area.

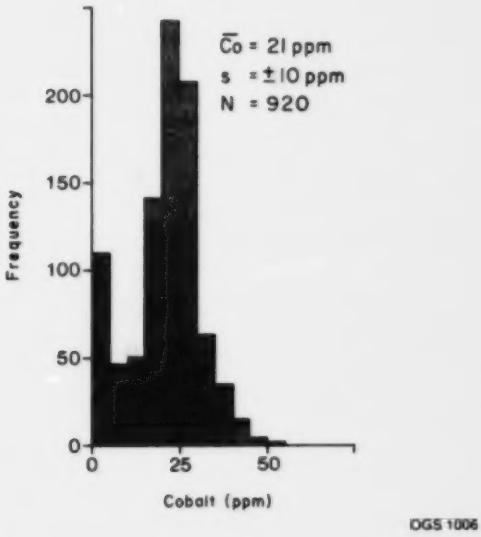


Figure 18–Histogram of cobalt abundance in volcanic rocks of the Clifford-Ben Nevis Townships area.

near the Canagau deposit and transport of glacial debris in a south-southeast direction along the crest and flanks of a southeast-trending topographic ridge. Average background Zn values are 23 ppm in minus 250-mesh till; 25 ppm in minus 80- plus 250-mesh heavy mineral separates, and 23 ppm in 'B' horizon soils. Background populations are approximately normally distributed in the 10-40 ppm zinc range.

Microscopic examination of the tetrabromethane heavy mineral concentrates revealed a complete absence of sulphide minerals. It is concluded that sulphide minerals are generally not present in otherwise "fresh" looking near-surface samples of permeable, well drained glacial till, implying that sulphide cations have been redistributed in the till by secondary weathering processes involving chemical and physical leaching by downward moving groundwater. Trace element analyses of heavy mineral concentrates therefore reflect nothing more than the metai concentrations of stable oxide minerals, primary silicate minerals and secondary iron and manganese oxides. This conclusion is supported by the observation that zinc concentrations in the minus 250-mesh fractions of anomalous tills in the Ben Nevis Township study area, are systematically significantly higher than those for related heavy minerals. Secondary oxides and clay minerals in the minus 250-mesh fraction have evidently scavenged Zn cations released by oxidation of sulphide minerals which, in unweathered samples, would have been present in the heavy mineral concentrates. Redistribution of Zn by processes of near-surface weathering and soil formation has, in terms of anomaly contrast, anomaly extent, and pattern homogeneity, produced better geochemical exploration results from 'B' horizon soil analyses than from heavy mineral analyses. Typical comparative data given in Table 4 illustrate the kinds of anomaly contrast expectable in three size fractions of 'C' horizon soils.

The Ben Nevis Township orientation study leads to the conclusions that:

(1) The nature of the pre-glacial bedrock topography immediately up-ice and for some distance down-ice from a mineralized bedrock source, has an important bearing on the nature and extent of erosion and transport by the ice.

(2) Secondary weathering processes play an extremely important role in the redistribution of mobile elements within the upper 1 to 2 m (3 to 6 feet) of permeable, well-drained silty to sandy boulder till. Analysis of heavy mineral concentrates from 'near-surface' samples of apparently unoxidized till may not always produce the best geochemical exploration results.

THE CHEMISTRY OF EARLY PRECAMBRIAN VOLCANIC ROCKS

In the Canadian Shield, Early Precambrian (Archean) volcanic assemblages of approximate age 2750 m.y. or older show well defined petrochemical progressions from lower primitive peridotitic lavas (Pyke *et al.* 1973) and Ca-Mg-rich basaltic komatiite (Brooks and Hart 1972; 1974) through tholeiitic lavas of moderate iron enrichment trends, to upper high-alumina calc-alkaline lavas (Goodwin 1973). The peridotitic and basaltic komatiites are not volumetrically im-

TABLE 3 | CHEMICAL ANALYSES OF VOLCANIC ROCKS – BEN NEVIS TOWNSHIP.

Major Elements	1	2	3	4	5	6	7	8
SiO_2	73.3	78.5	57.8	60.0	71.1	55.5	51.5	56.1
Al_2O_3	14.2	11.1	17.0	15.8	15.3	16.7	14.4	15.1
Fe_2O_3	0.41	0.22	1.05	0.58	0.50	1.35	1.03	1.66
FeO	1.25	1.53	3.41	5.15	2.85	6.15	4.88	5.78
MgO	0.80	0.68	1.62	3.16	1.50	6.93	4.40	6.20
CaO	2.25	1.08	13.0	5.32	1.78	5.81	11.2	6.95
Na_2O	2.86	1.90	1.55	1.33	2.52	3.68	2.29	0.94
K_2O	2.53	2.89	0.28	1.52	2.24	0.38	0.99	1.36
H_2O^+	1.41	1.26	3.13	3.29	2.12	3.66	3.03	4.45
H_2O^-	0.04	0.06	0.11	0.06	0.10	0.14	0.05	0.18
CO_2	1.30	0.54	0.24	3.43	0.98	0.28	6.40	0.26
TiO_2	0.21	0.14	1.30	0.93	0.36	0.90	0.74	0.92
P_2O_5	0.04	0.03	0.12	0.19	0.07	0.11	0.10	0.14
S	0.04	0.01	0.02	0.14	0.10	–	0.01	–
MnO	0.02	0.04	0.10	0.19	0.09	0.12	0.14	0.13
Total	100.7	100.0	100.7	101.1	101.6	101.7	101.2	100.2
Trace Elements								
Ag (1)*	–	–	–	–	–	–	–	–
As (3)	3	–	4	15	4	–	5	6
Ba (150)	300	400	–	300	300	150	200	300
Co (5)	–	–	30	8	–	30	20	30
Cr (10)	–	–	200	–	–	230	50	50
Cu	8	6	8	25	5	45	45	55
Ga	20	15	15	20	20	15	15	15
Li (20)	–	–	–	–	–	–	–	–
Mo (10)	–	–	–	–	–	–	–	–
Ni (5)	–	–	130	–	–	130	90	100
Pb (10)	15	–	–	–	10	–	–	–
Sb (1)	–	–	–	–	–	–	–	–
Sc (20)	–	–	30	–	–	20	–	–
Sr	40	20	20	90	25	200	250	150
V (10)	–	–	350	70	–	200	200	200
Y (20)	25	20	–	40	30	–	–	–
Zn	50	40	40	150	50	75	60	75
Zr	150	150	100	250	150	100	130	130
Be (3)	–	–	–	–	–	–	–	–
Sn (10)	–	–	–	–	–	–	–	–

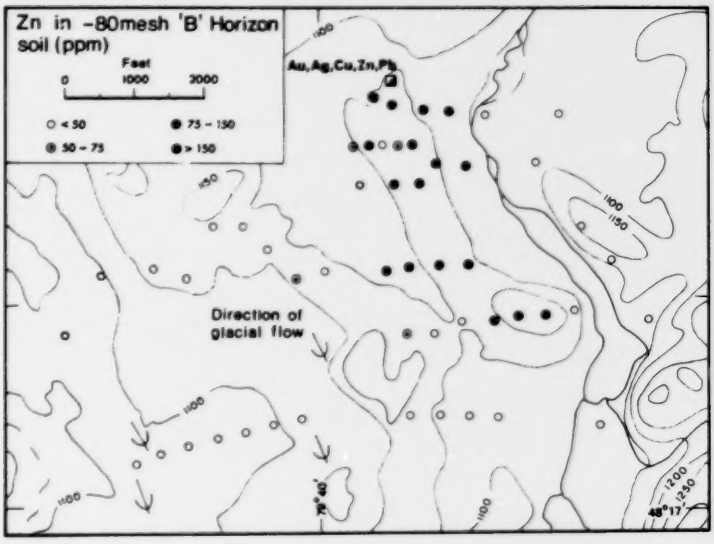
Chemical Classification[a]	Longitude*	Latitude*
1. Calc-alkaline dacite	79-39-13.1	48-19-15.5
2. Calc-alkaline dacite	79-39-05.4	48-19-30.5
3. Tholeiitic basalt	79-38-43.8	48-19-49.6
4. Tholeiitic basalt	79-38-30.0	48-20-09.8
5. Calc-alkaline dacite	79-39-51.5	48-18-39.3
6. Calc-alkaline basalt	79-40-36.1	48-18-08.8
7. Tholeiitic basalt	79-41-02.3	48-17-56.9
8. Tholeiitic basalt	79-39-06.9	48-17-38.9
9. Calc-alkaline andesite	79-40-36.1	48-17-04.7
10. Calc-alkaline andesite	79-04-58.4	48-17-09.3
11. Calc-alkaline andesite	79-41-08.5	48-17-18.1
12. Tholeiitic basalt	79-41-20.8	48-17-34.1
13. Calc-alkaline andesite	79-41-37.7	48-17-37.2

9	10	11	12	13	14	15	16	17
55.0	56.3	54.4	48.1	58.0	54.4	48.6	45.7	50.4
15.4	15.6	17.7	15.5	15.9	16.7	16.6	18.2	14.2
2.14	1.26	1.14	3.04	1.13	1.41	0.98	1.83	0.72
5.43	5.92	5.36	8.42	5.57	5.43	11.9	8.07	7.31
5.96	5.73	5.10	6.93	5.17	4.75	9.54	5.17	7.09
6.16	5.42	6.33	10.3	5.90	8.12	0.41	4.20	6.80
3.79	4.35	4.84	1.67	3.37	3.14	0.14	1.27	1.10
0.07	0.07	0.05	0.38	0.93	0.13	0.88	1.92	0.81
3.82	3.18	3.49	2.88	4.02	3.58	7.21	4.91	5.15
0.08	0.05	0.12	0.15	0.10	0.12	0.04	0.08	0.15
1.06	0.31	0.68	0.38	0.48	0.30	0.12	5.88	5.26
1.00	1.00	0.94	1.05	0.79	0.87	1.12	1.20	0.91
0.16	0.15	0.11	0.06	0.08	0.10	0.16	0.10	0.13
0.01	0.02	0.01	0.12	0.02	0.01	0.13	0.91	0.05
0.12	0.10	0.12	0.20	0.11	0.11	0.40	0.17	0.27
100.2	99.5	100.4	99.2	101.6	99.2	98.2	99.6	100.4
–	–	–	–	–	–	1	–	–
6	–	7	–	–	–	70	50	30
–	–	–	–	200	–	200	250	150
30	30	20	40	20	25	35	35	25
120	80	50	300	20	50	140	120	100
45	45	50	120	45	50	15	45	30
15	20	30	20	25	20	25	25	20
–	–	–	–	–	–	70	40	30
–	–	–	–	–	–	–	–	–
100	110	45	110	85	100	110	80	70
–	–	–	–	–	–	1040	10	20
–	–	–	–	–	–	2	2	–
20	–	20	40	–	–	20	35	20
300	250	150	100	150	200	10	100	40
250	150	150	250	100	150	150	200	150
20	20	20	20	–	–	–	20	–
85	86	60	80	65	75	2440	150	240
150	150	130	60	80	150	150	130	130
–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	30	–	–

Chemical Classification[a]	Longitude*	Latitude*
14. Calc-alkaline basalt	79-41-26.9	48-17-20.7
15. Calc-alkaline basalt	79-39-37.7	48-19-03.6
16. Calc-alkaline basalt	79-39-44.6	48-19-01.0
17. Tholeiitic basalt	79-39-44.6	48-19-01.0

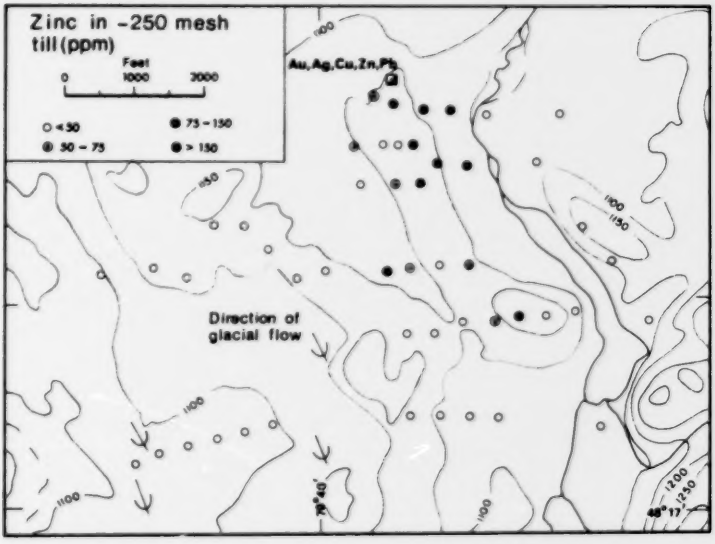
[a]Terminology follows classification of Irving and Baragar.
*79-39-51.5 = 79°39′51.5″

Analyses by Mineral Research Branch, using the following methods.
SiO_2, Al_2O_3, Total Fe, MgO, CaO, TiO_2 and MnO by X-Ray Fluorescence.
FeO, Na_2O, K_2O, H_2O^+, H_2O^-, CO_2, P_2O_5 and S by wet chemical (gravimetric and titration techniques).
As, Sb by colorimetric titration.
Ag, Ba, Cr, Ga, Li, Mo, Sc, Sr, V, Y, Zr, Be, Sn by emission spectroscopy.
Co, Cu, Ni, Pb and Zn by atomic absorption spectroscopy.
Fe_2O_3 by subtraction (Total Fe – FeO).
*Lower detection limits (sensitivities) shown in brackets.



OGS 1007

Figure 19–Zinc content in minus 80-mesh 'B' horizon soil down-ice from the Canagau Mines Ltd. Zn-Cu-Pb-Ag-Au deposit. Contours are topographic elevations in feet.



OGS 1008

Figure 20–Zinc content in minus 250-mesh glacial till down-ice from the Canagau Mines Ltd. Zn-Cu-Pb-Ag-Au deposit. Contours are topographic elevations in feet.

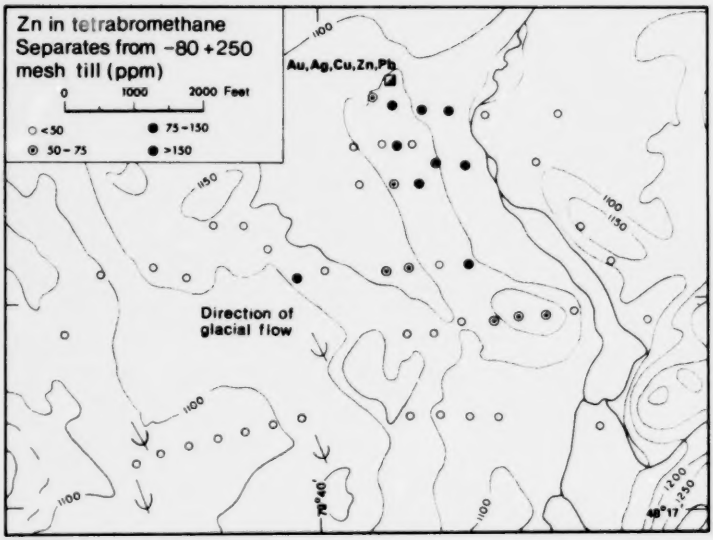


Figure 21–Zinc content in tetrabromoethane heavy mineral separates from the minus 80-mesh, plus 250-mesh fraction of glacial till down-ice from the Canagau Mines Ltd. deposit. Contours are topographic elevations in feet.

portant in most Early Precambrian volcanic successions. Their existence is mainly significant in terms of explaining tectonic environments (e.g. steep geothermal gradient, high convection rates, thin lithospheric plates) peculiar to Early Precambrian time. Sub-alkaline mafic to felsic flows and pyroclastics of tholeiitic to calc-alkaline affinity predominate in the volcanic belts but some alkalic volcanic rocks are present in the Kirkland Lake region of the Abitibi Belt (Cooke and Moorhouse 1969).

Large numbers of chemical analyses of Early Precambrian volcanic rocks from widespread areas of the Canadian Shield have consistently shown the same petrochemical characteristics (Wilson *et al.* 1965; Goodwin 1967, 1968, 1970; Baragar 1966, 1968; Descarreaux 1972; Barlow 1973; Wolfe 1976). Chemical trends originate well within the tholeiitic field when projected onto the base of the Diopside-Olivine-Nepheline-Quartz tetrahedron of Yoder and Tilley (1962) and the major trend is sharply directed towards quartz enrichment (Baragar 1972). Early Precambrian volcanic rocks compare in part, with continental tholeiites and in part with the calc-alkaline basalt-andesite-rhyolite association common in the orogenically active regions of the continental margins including the island arc systems (Wilson *et al.*1965). When chemical analyses of Early Precambrian volcanic rocks are plotted on the standard AFM diagram (Figure 22), elements of both tholeiitic and calc-alkaline trends are recognized. Tholeiitic trends represented by iron enrichment relative to magnesium can usually be easily identified in the thick sequences of subaqueous, Fe-rich, pillowed basalts and andesites in

TABLE 4 ANOMALOUS AND BACKGROUND ZINC VALUES IN THREE SIZE FRACTIONS OF 'C' HORIZON SOILS.

Mesh Size Interval	Zinc Content (ppm) 1	2	3	4
-80 +120 m.	170	69	24	29
-120 +250 m.	197	86	26	26
-250 m.	360	135	26	25

Note: samples analysed by atomic absorption following hot aqua regia leach.
Samples 1 and 2 represent anomalous Zn levels.
Samples 3 and 4 represent background Zn levels.

the lower part of Early Precambrian volcanic cycles. Calc-alkaline trends represented by alkali enrichment without significant iron enrichment are recognizable in the upper, felsic pyroclastic parts of the cycles. Although both major trends are evident in Figure 22, there is a wide scatter of points and general lack of coherent differentiation trends that characterize younger volcanic suites. These features lead to uncertainty in the classification of analyses that plot near the tholeiitic-calc-alkaline boundary as defined by Irvine and Baragar (1971). Recognition of these two differentiation trends at the regional level is of some importance because most of the important Precambrian volcanogenic massive sulphide deposits of the Canadian Shield are associated with rocks of calc-alkaline affinity.

In Figure 22, analyses of 1,041 Early Precambrian volcanic rocks obtained from reports by Goodwin (1967, 1970) and Wolfe (1976) and from unpublished thesis studies by Barlow (1973) and Descarreaux (1972) are plotted in the standard AFM ternary diagram. From this group of analyses, those containing (FeO + 0.9 Fe_2O_3) in excess of 10.0 percent by weight were extracted and re-plotted separately in the diagram shown at the right of Figure 22. All but 16 of these high-iron Early Precambrian volcanic rocks plotted in the tholeiitic field of the AFM diagram as defined by the dividing line suggested by Irvine and Baragar (1971). For Early Precambrian volcanic rocks with low to moderate Mg/Fe ratios the total iron content expressed as FeO appears to discriminate well between rocks of tholeiitic and calc-alkaline affinity.

ZINC ABUNDANCE IN EARLY PRECAMBRIAN VOLCANIC ROCKS

A survey of 1,041 complete and 1,472 partial chemical analyses of Early Precambrian tholeiitic and calc-alkaline volcanic rocks from the Abitibi, Wawa, Wabigoon and Uchi Belts of the Superior Province of the Canadian Shield has demonstrated certain regularities in the abundance and distribution of zinc. Statistical distributions of zinc in groups of volcanic rocks from six areas within these belts are shown in Figure 23. Zinc abundances range from 3 ppm to about 200 ppm in background volcanic rocks remote from mineralization and much of

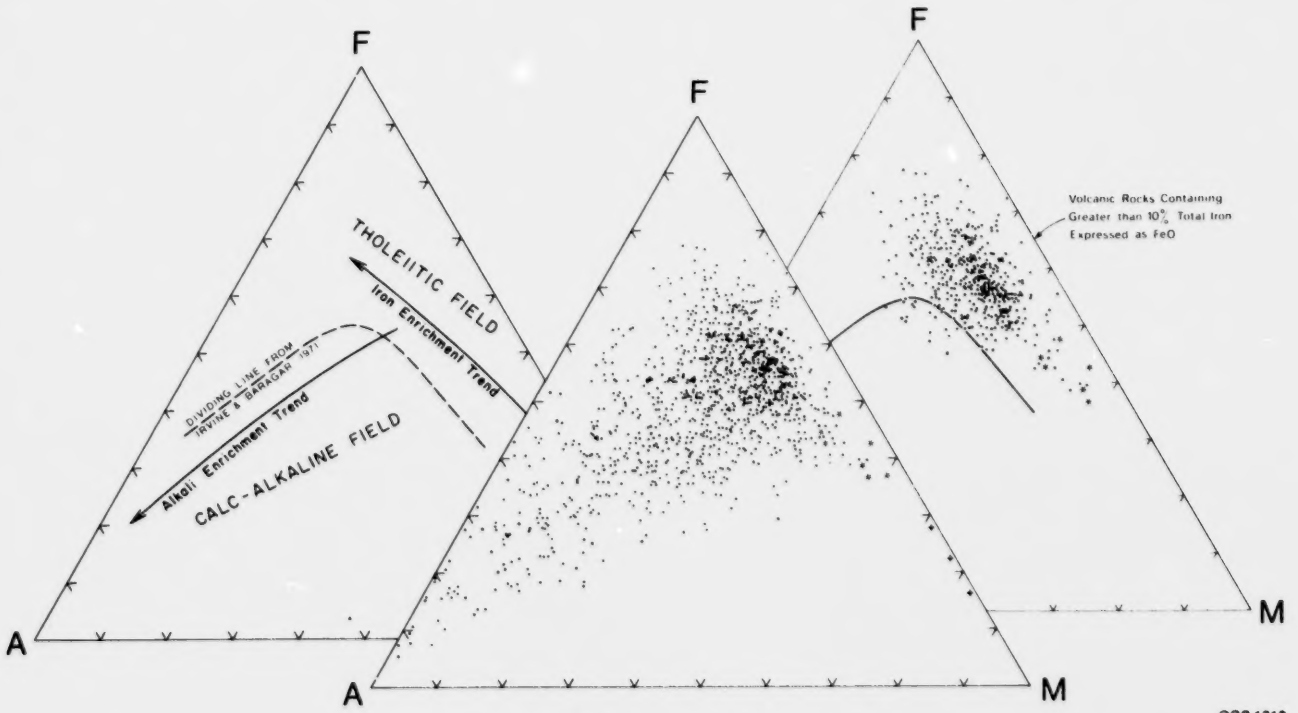


Figure 22–AFM plots showing patterns of variation in 1,041 samples of Early Precambrian tholeiitic and calc-alkaline volcanic rocks. A = Na_2O + K_2O; F = FeO + 0.9 Fe_2O_3; M = MgO, all in weight percent. Samples containing F greater than 10 percent are plotted separately in the diagram at the right. * = basaltic komatiite defined by MgO greater than 9.0 percent and CaO/Al_2O_3 ratio greater than one. + = analyses of extrusive ultramafic flows from Pyke *et al.* (1973).

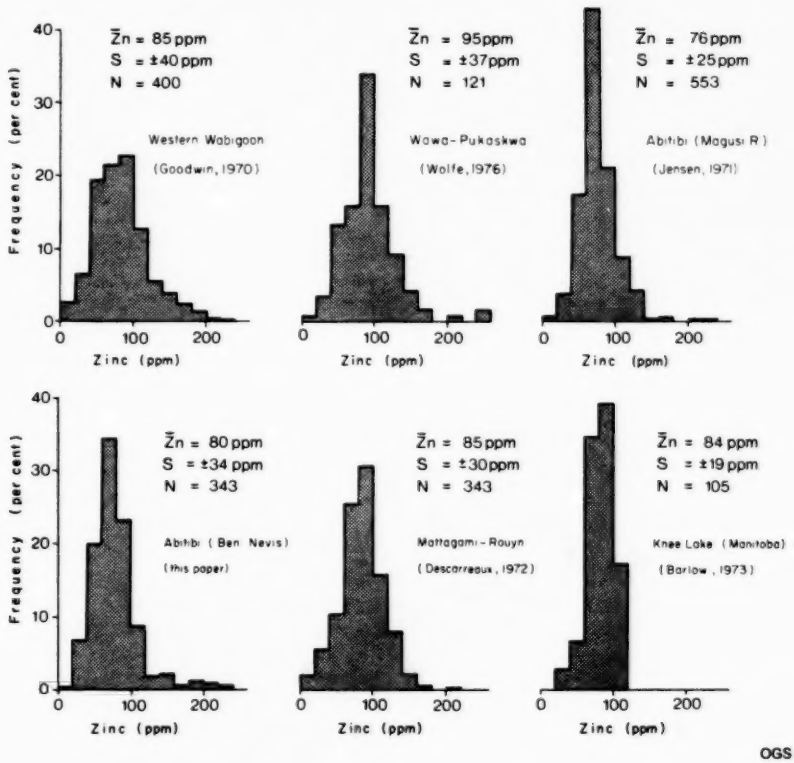


Figure 23–Histograms of zinc abundance in volcanic rocks from six areas within Early Precambrian belts of the Superior Province.

this variation is explained by processes of magma differentiation represented by the variables SiO_2 and total iron (expressed as FeO and herein designated as FeO*).

The average zinc contents of sampled areas in the volcanic belts vary from 80 to 95 ppm and Zn frequency distributions closely approximate a normal form. In the upper tails of the histograms (Figure 23), zinc values in the range of 120-200 ppm are invariably identified with high-iron tholeiitic basalts containing FeO* in excess of 10.0 percent. In the lower tails, Zn values in the 3-50 ppm range represent siliceous dacites and rhyolites of low iron content. The small differences in the statistical characteristics of the six Zn populations may in part be due to systematic inter-laboratory error. More generally, however, these differences are caused by unweighted comparisons between different areas containing unrepresentative proportions of high Fe-Zn tholeiitic basalts and low Fe-Zn calc-alkaline volcanic rocks. The Wabigoon, Pukaskwa and Mattagami-Rouyn populations include a significant number of Fe-rich tholeiites and have high average Zn abundances of 85, 95, and 85 ppm respectively. Samples in these

three groups were collected over large areas of 1,000 km^2 or more and therefore accurately represent the overall composition of Early Precambrian volcanic belts. In comparison, the Magusi River and Ben Nevis Township populations represent localized areas within the Abitibi Belt that are dominated by calc-alkaline volcanic rocks of relatively lower average Fe-Zn content.

Statistical correlations of the type shown in Table 5 were used to test the degree to which metal concentrations were dependent on chemical parameters which could be tied to the fractional crystallization process. As expected, total Fe as FeO, MgO, Normative Color Index (C.I.), Zn and log Zn all show strong negative linear correlation coefficients with respect to SiO_2. The degree of correlation between Zn and SiO_2 is a good deal better than that between Cu and SiO_2 because in background volcanic rocks, sphalerite is a relatively rare mineral and Zn occurs primarily in mafic silicates and oxide minerals as a substitute for iron. In comparison, data obtained by sulphide selective digestion of rock samples, indicate that Cu occurs almost exclusively in the form of chalcopyrite. On the basis of the above information, SiO_2 was selected as the best single indicator of the differentiation process and plots of SiO_2 vs. Zn were used to express zinc variability in unmineralized differentiated sequences of Early Precambrian volcanic rocks.

In Figure 24, zinc variation is plotted as a function of the SiO_2 content in 1,575 samples of Archean volcanic rocks. The chemical data used to construct this plot were obtained from various published and unpublished sources including Goodwin (1970), Descarreaux (1972), Wolfe (1976), Barlow (1973) and Division of Mines geochemical files. The Zn content of basaltic rocks (45-52 percent SiO_2) varies widely between 50 ppm and 200 ppm and in a general way shows a positive relationship to the iron content of these rocks. The average Zn content of andesites remains essentially constant at about 85 ppm over the silica range of 52-60 percent. At silica levels above 60 percent, Zn decreases linearly to a mean value of about 35 ppm in rhyolitic volcanic rocks containing 75 percent SiO_2. The trend shown by the heavy line in Figure 24 represents Zn variation attributable to differentiation processes in unmineralized suites of Early Precambrian tholeiitic and calc-alkaline volcanic rocks. A field drawn to enclose the plotted points defines the range of expectable Zn-SiO_2 variation in normal Early Precambrian volcanic rocks. Analyses falling outside the upper boundary of this field therefore are presumed to reflect abnormal zinc concentrations connected with a mineralizing process.

Because Precambrian volcanogenic massive sulphide deposits are typically associated with calc-alkaline volcanic sequences (Sangster 1972) and are notably absent in the Fe-rich basaltic lavas in the lower parts of Early Precambrian volcanic successions, Figure 24 can be further refined by discarding all analyses containing more than 10.0 percent FeO*. When this is done, as in Figure 25, the average zinc content of the remaining low-Fe mafic volcanic rocks remains essentially constant at 85 ppm throughout the silica range of 45-60 percent. The upper limit of normal zinc variation in calc-alkaline volcanic sequences is therefore not likely to exceed 125 ppm.

To test the ability of plots such as that shown in Figure 25 to discriminate between barren and mineralized volcanic environments, a number of samples collected by A.M. Goodwin from acid volcanic cycles in the Uchi-Confederation Lakes area of northwestern Ontario were analyzed for zinc. Silica values for these samples were previously reported by Goodwin (1967). Both the upper and lower acid volcanic cycles contain massive Zn-Cu-Ag sulphide deposits but the

TABLE 5 CHEMICAL CORRELATIONS IN 400 EARLY PRECAMBRIAN VOLCANIC ROCKS – NORTHWESTERN ONTARIO: TABLE OF CORRELATION COEFFICIENTS.

	SiO_2	FeO	MgO	FeO + MgO	C.I.*	Zn
FeO	-0.87	–	–	–	–	–
MgO	-0.74	0.56	–	–	–	–
C.I.*	-0.92	0.83	0.88	0.96	–	–
Zn	-0.62	0.66	0.38	0.61	0.55	–
log Zn	-0.67	0.66	–	–	–	–
Cu	-0.40	0.37	0.27	0.37	0.38	0.32

*C.I. = Normative color index (sum of normative mafic minerals).

only producing mine, the South Bay deposit of Selco Mining Corporation Limited, is located within the upper acid cycle. As shown in Figure 26, all of the analyzed samples from the upper cycle contained anomalously high levels of zinc. In addition, 7 of 21 samples from the lower cycle were identified as being anomalously high in zinc. In a more extensive study of the geochemistry of volcanic rocks in the Birch-Uchi Lakes area, Davenport and Nichol (1973) reached similar conclusions regarding the anomalous nature of the upper volcanic cycle. Also shown in Figure 26, are Zn vs. SiO_2 plots for six samples of massive rhyolite and rhyolitic volcanoclastic rocks from the stratigraphic footwall of the Kidd Creek massive sulphide deposit near Timmins, Ontario. Four of the six samples collected from outcrop located 122 m (400 feet) east of the Kidd Creek pit, are clearly identified as anomalous in zinc.

Figure 27 illustrates Zn and SiO_2 variation in a group of 359 samples of volcanic rocks from the Ben Nevis Township map-area. Although silica varies from 45.6 to 83.0 percent, FeO* never exceeds 10.0 percent in this group of calc-alkaline volcanic rocks. Anomalous Zn concentrations are therefore defined in samples which plot outside the field of normal Zn-SiO_2 variation in low FeO* volcanic rocks (Figure 25). By plotting the locations of *only* the samples identified as zinc anomalous in Figure 27, regional background variations are removed and clustering of zinc values related to sulphide mineralizing processes is enhanced (Figure 28).

CONCLUSIONS

Trace metal dispersion haloes in Early Precambrian volcanic rocks are produced by the passage of hydrothermal metal-transporting fluids through pipes and vents connected with massive sulphide mineral formation by metal exhalations at the sea floor surface. These metal-exhalative processes therefore superimpose locally anomalous geochemical patterns on regional rock chemistry trends that are explainable by normal magma differentiation. In differentiated basalt-andesite-dacite-rhyolite volcanic suites, most of the trace metal cations

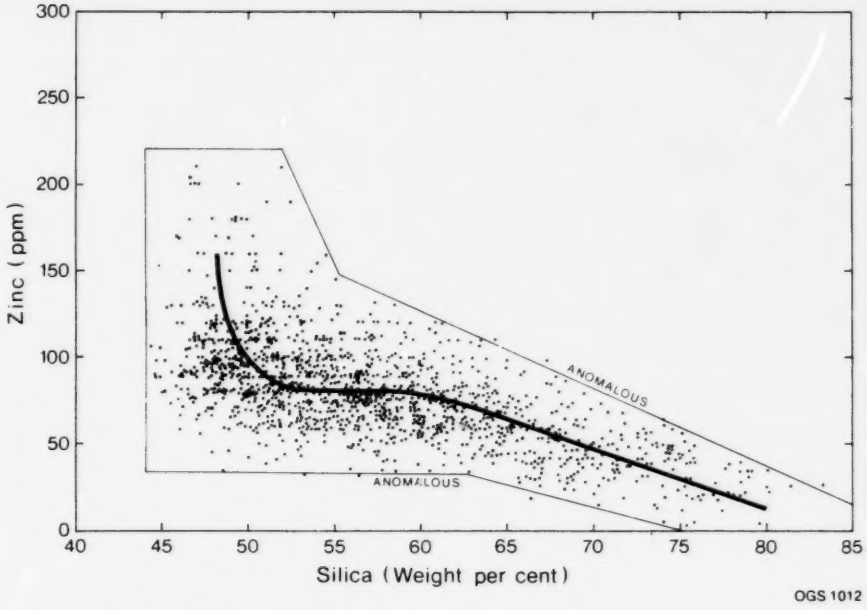


Figure 24–Plot of Zn versus SiO_2 in 1575 samples of Early Precambrian volcanic rocks.

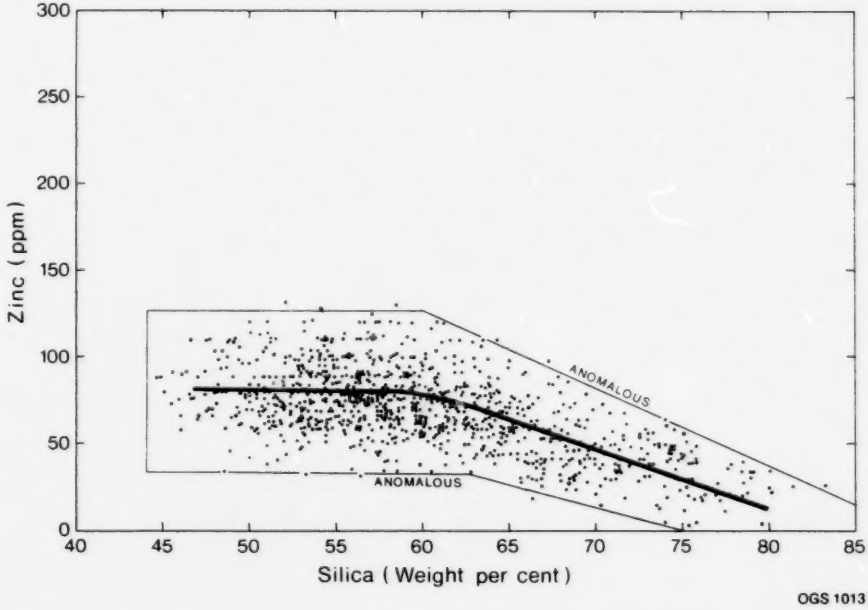


Figure 25–Plot of Zn versus SiO_2 in Early Precambrian volcanic rocks containing less than 10.0 percent FeO*.

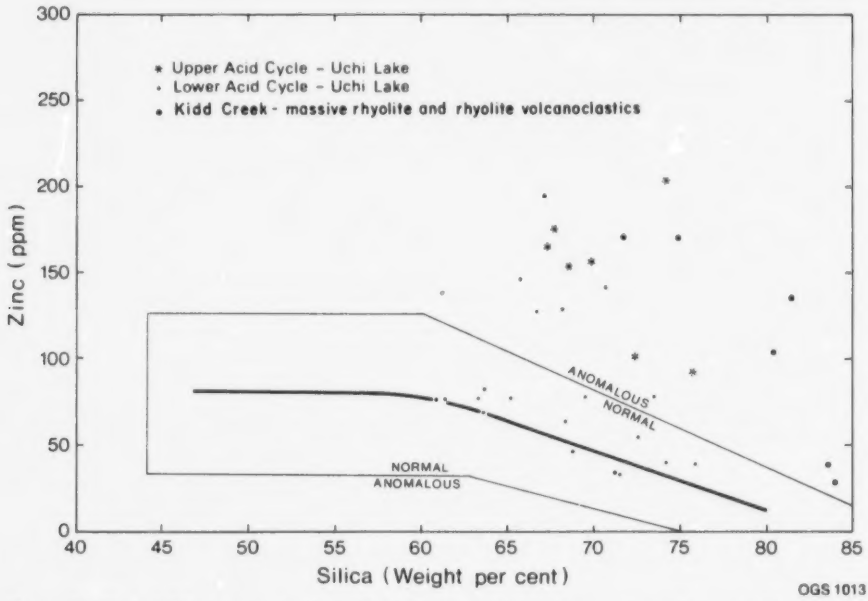


Figure 26–Plot of SiO_2 in samples from Kidd Creek, and from the upper and lower acid cycles of the Uchi-Confederation Lake metavolcanic belt.

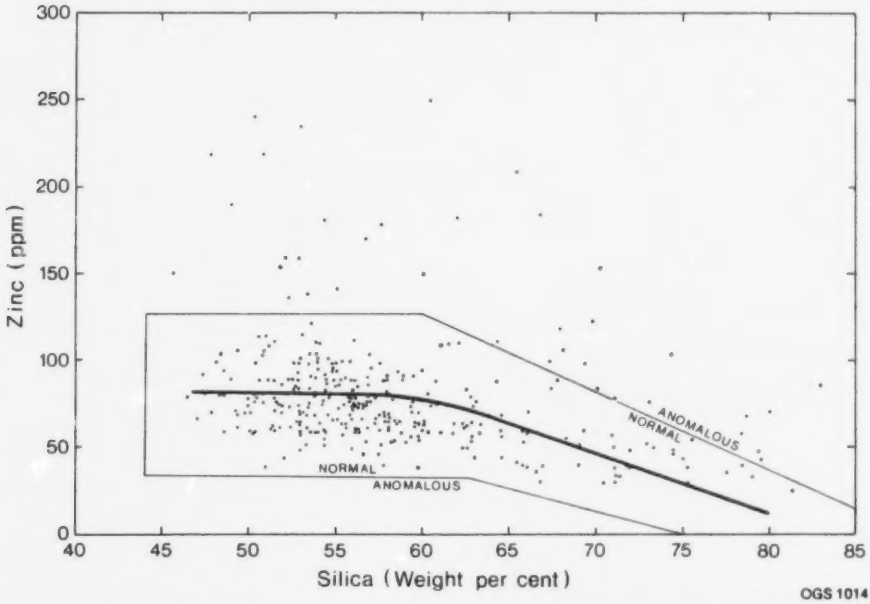


Figure 27–Plot of Zn versus SiO_2 in 359 samples of Early Precambrian calc-alkaline volcanic rocks from the Ben Nevis Township area. All samples contain less than 10.0 percent FeO*.

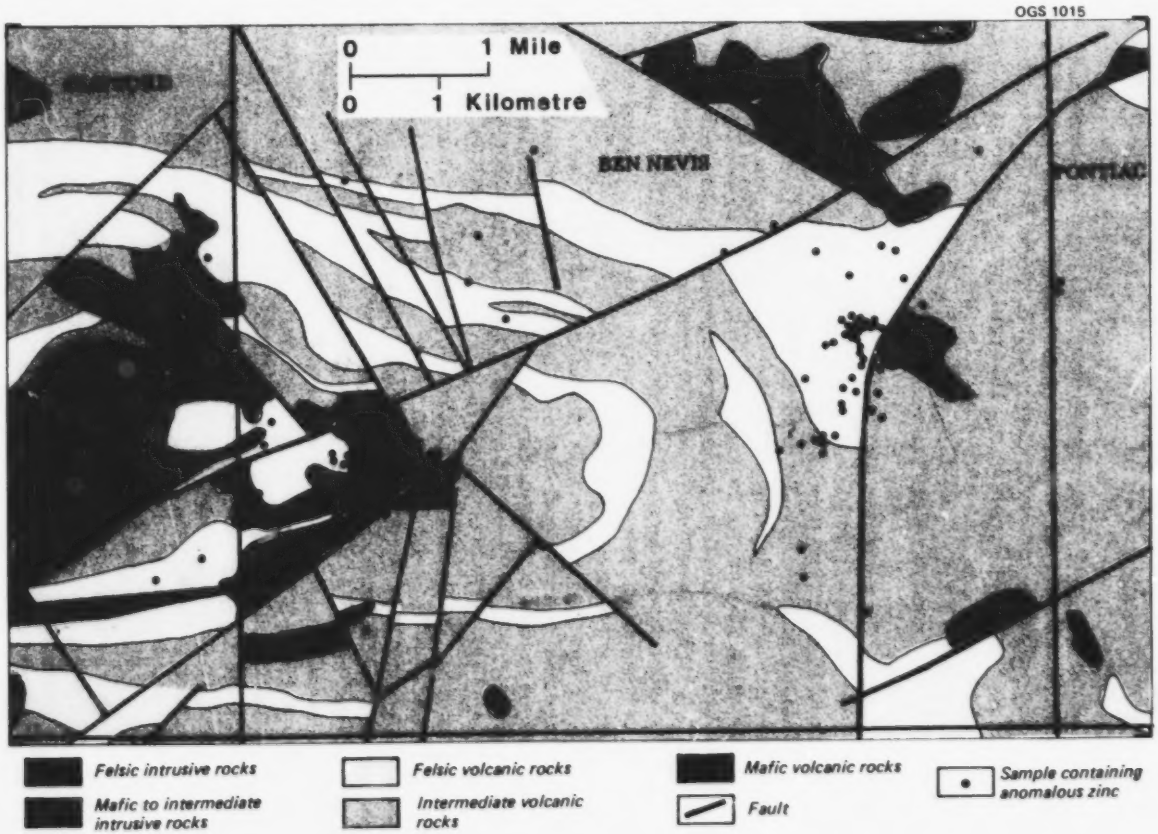


Figure 28–Areal distribution of samples from the Ben Nevis Township area containing anomalous zinc as defined by Figure 27.

(Cu, Zn, Ni, Co, Mn) show systematic and predictable depletion with increasing SiO_2 and decreasing total Fe. Copper in unmineralized volcanic rocks occurs almost exclusively in sulphide phases (mainly chalcopyrite) while Ni, Co and Mn are distributed in significant proportions in oxides and in the octahedral Fe-Mg sites of mafic silicate phases. Zinc displays a much less chalcophile behaviour than copper, and sphalerite is extremely rare in normal unmineralized rocks. In Early Precambrian volcanic sequences, Zn varies systematically from 125-200 ppm in high-Fe tholeiitic basalts to an average of 85 ppm in low-Fe basalts and andesites, and an average of 35 ppm in rhyolites containing 75 percent SiO_2. By relating Zn concentrations to SiO_2 and total Fe content, it has been possible to separate components of Zn variation due to the silicate fractional crystallization process, from locally anomalous Zn variation attributable to base metal ore-forming processes.

In the Ben Nevis Township area, the residual Zn and Cu values provide a reliable guide to disseminated sphalerite-chalcopyrite mineralization in alteration pipes and haloes. More limited data suggest that the elements arsenic, antimony, lead, lithium, tin and mercury also occur in anomalously high concentrations in zones of sericite-chlorite-talc-carbonate alteration surrounding known base metal mineralization. Nickel, manganese and cobalt are not suitable indicators of Zn-Cu-Pb-Ag-Au sulphide mineralization in the calc-alkaline volcanic environment of Ben Nevis Township. These elements are, however, sensitive to changes in the bulk major element chemistry of unmineralized differentiated igneous rocks. In terms of anomaly contrast, anomaly extent (i.e. dispersion), and pattern homogeneity, no element appears to provide a significantly better guide to mineralization than the simple and direct method of zinc analysis.

The average zinc abundance in Superior Province Early Precambrian volcanic belts ranges from 80 to 95 ppm. Zinc histograms showing frequency distribution of values, show a predictable approximately normal (bell-shaped) form symmetrical about the arithmetic mean. The occurrence of positive skewness introduced by samples containing more than 200 ppm zinc, is almost certainly the result of a superimposed mineralizing event.

Examination of over 1,000 complete chemical analyses of Early Precambrian volcanic rocks shows that in rocks of low to moderate Mg/Fe ratio, the total iron content expressed as FeO is almost as good a discriminator between tholeiitic and calc-alkaline suites as the more conventional AFM diagram.

Geochemical analyses of 'B' horizon soil and components of glacial till down-ice from a known mineralized bedrock source indicate:

(1)That pre-glacial topography immediately up-ice and for some distance down-ice from a mineralized sub-cropping source, has an important influence on the nature and extent of erosion and transport by the ice.

(2)That secondary post-glacial weathering has been extremely important in the redistribution of mobile trace elements in the upper 1 to 2 m (3 to 6 feet) of permeable, well-drained, silty to sandy boulder till. Sulphide minerals are completely leached from the heavy mineral fraction of gray, apparently unoxidized samples of near-surface till.

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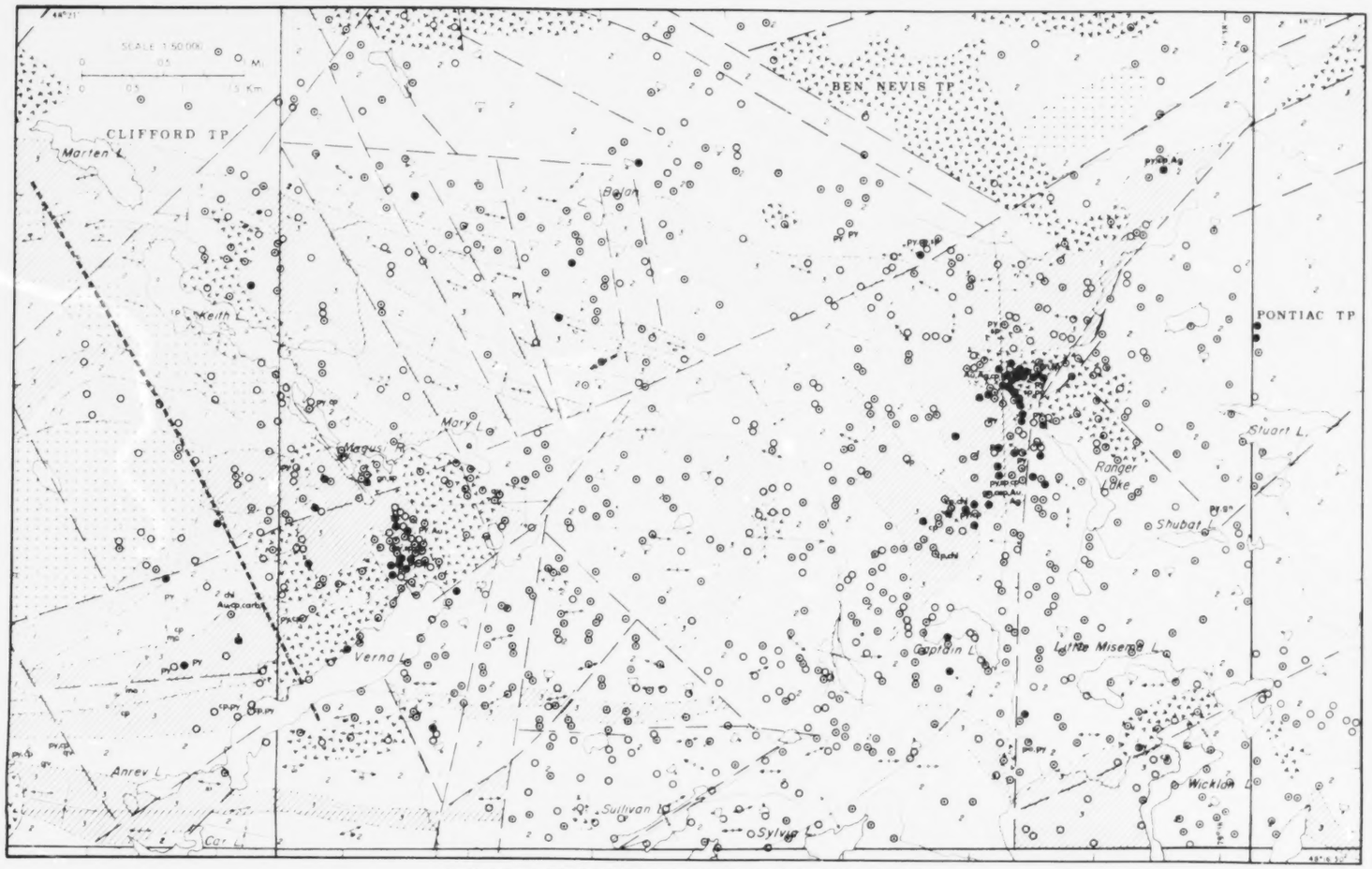


FIGURE 7 – ZINC CONCENTRATIONS IN VOLCANIC ROCKS.

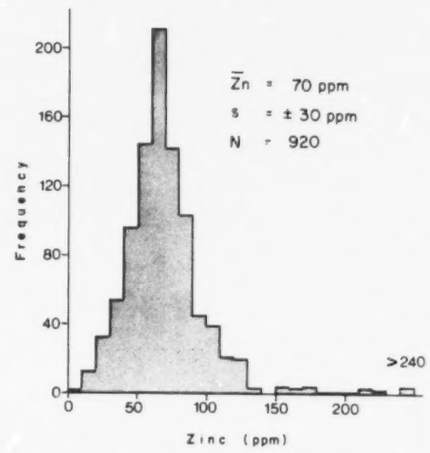
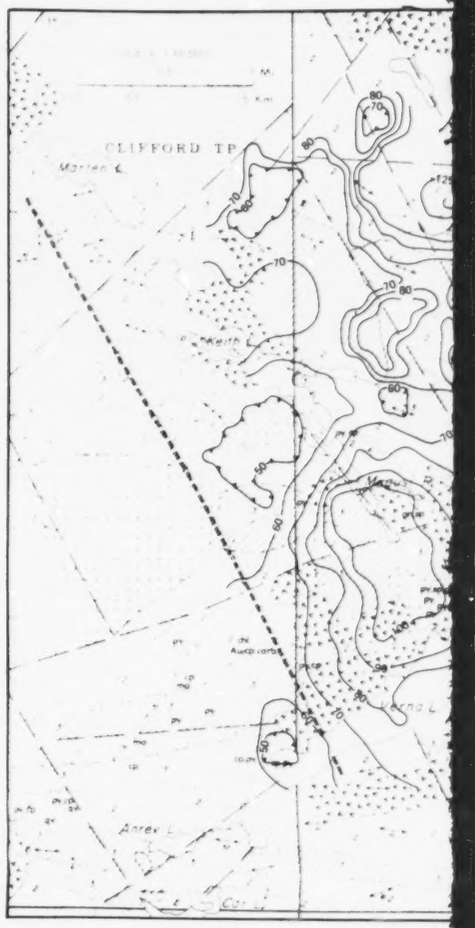


Figure 8 – Histogram of ZINC abundance in volcanic rocks.

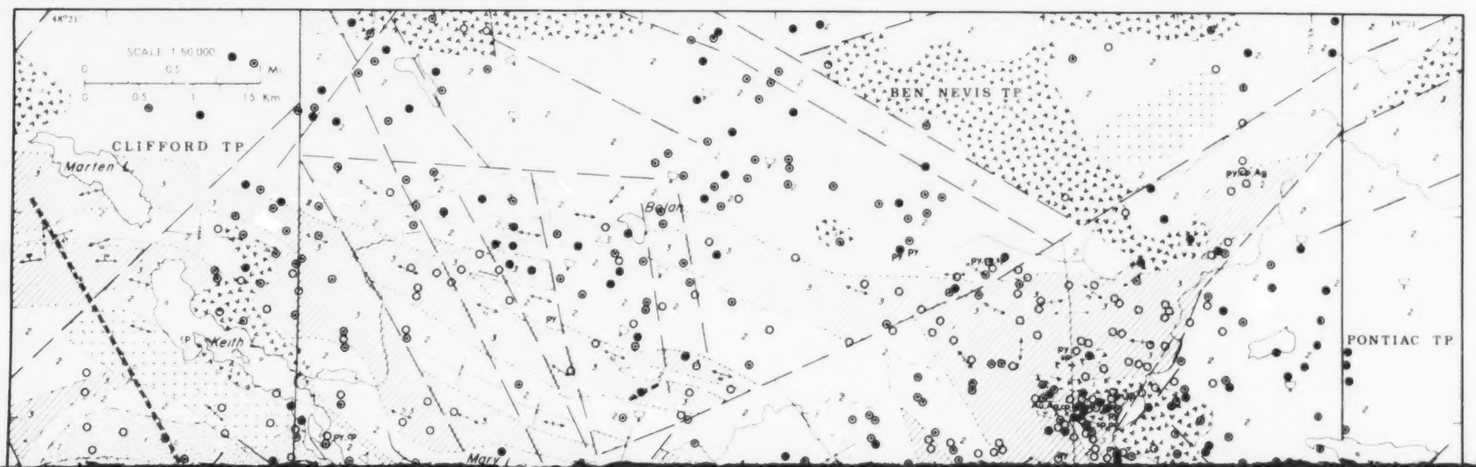
Contours of Zn concentration (50, 60, 70, 80, 90, 100, 125, 150, 200, 250, ppm)

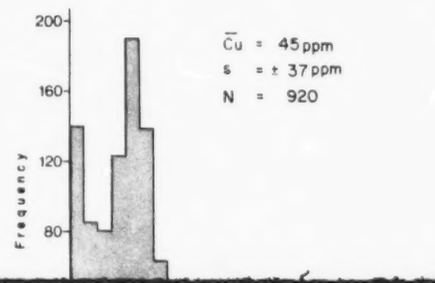
GEOCHEMICAL SYMBOLS

- ○ Less than 60 ppm zinc
- ⊙ 60-120 ppm zinc
- ● 120-240 ppm zinc
- ● Greater than 240 ppm zinc

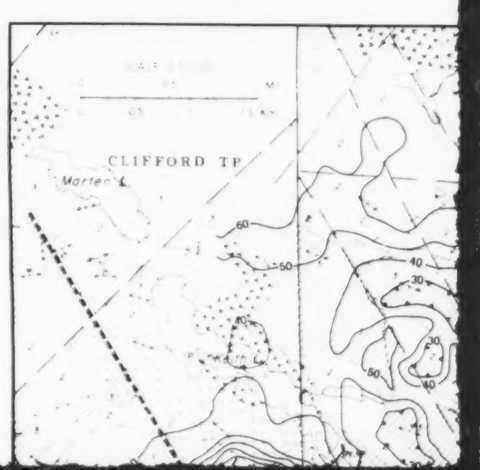


FIGURE





Contours of Cu concentration (30, 40, 50, 60, 70, 80, 90, 100, 125, 150, ppm)



Contours of Zn concentration (50, 60, 70, 80, 90, 100, 125, 150, 200, 250, ppm)

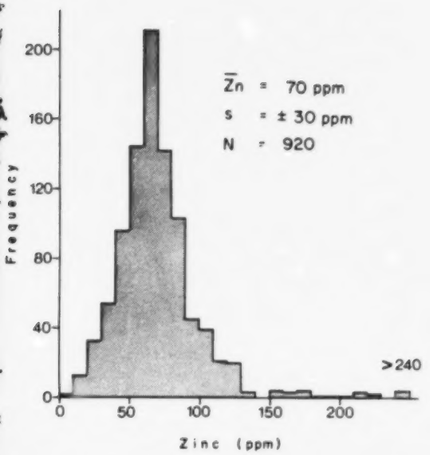


Figure 8 – Histogram of ZINC abundance in volcanic rocks.

GEOCHEMICAL SYMBOLS

- Less than 60 ppm zinc
- 60-120 ppm zinc
- 120-240 ppm zinc
- Greater than 240 ppm zinc

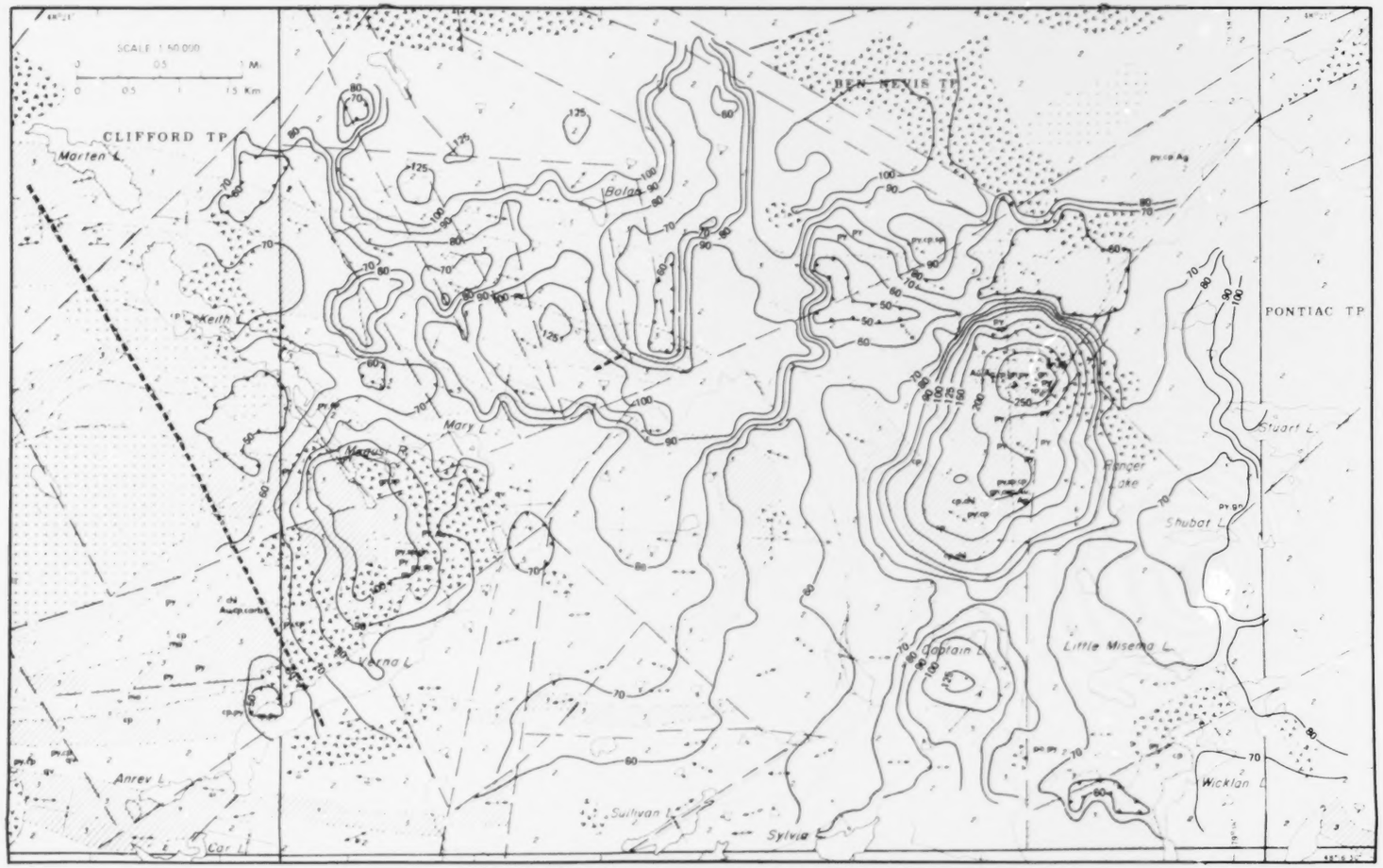
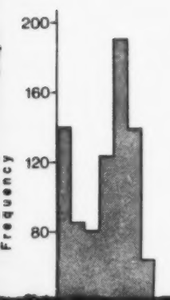
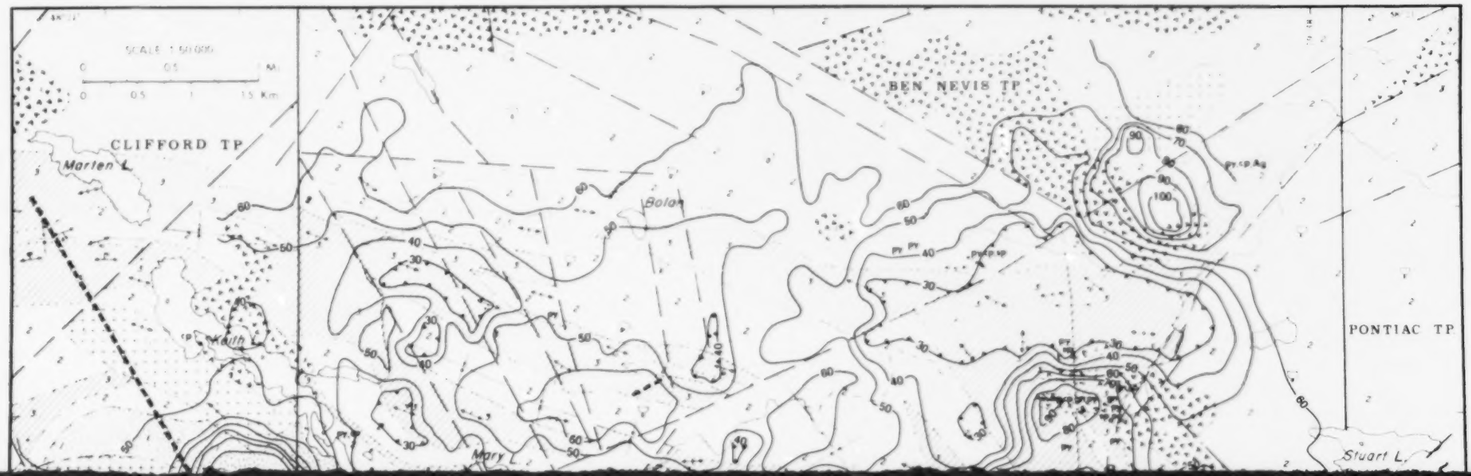


FIGURE 9 – REGIONAL MOVING AVERAGE TRENDS OF ZINC DISTRIBUTION (PPM).

Contours of Cu concentration (30, 40, 50, 60, 70, 80, 90, 100, 125, 150, ppm)





Ontario Geological Survey Study GS19
Geochemical Exploration of Early Precambrian Volcanogenic Sulphide Mineralization in Ben Nevis Township
Chart A
Figures 7, 8, 9, 10, 11, 12, 13, 14, 15

CHART A

Geochemical Distribution of ZINC, COPPER, AND NICKEL IN VOLCANIC ROCKS

BEN NEVIS TOWNSHIP
and parts of Clifford and Pontiac Townships

DISTRICT OF COCHRANE

GEOLOGICAL LEGEND

CENOZOIC
QUATERNARY
PLEISTOCENE AND RECENT*

Stream, lake, and swamp deposits; Glacial, glaciofluvial, and glaciolacustrine deposits (clay, sand, and gravel)

UNCONFORMITY

PRECAMBRIAN
MIDDLE TO LATE PRECAMBRIAN (PROTEROZOIC)
MAFIC INTRUSIVE ROCKS

6 — Olivine diabase, quartz diabase

INTRUSIVE CONTACT

EARLY PRECAMBRIAN (ARCHEAN)
FELSIC INTRUSIVE ROCKS

5 — Granodiorite, quartz diorite, diorite, syenite, feldspar porphyry and quartz-feldspar porphyry

INTRUSIVE CONTACT

MAFIC TO INTERMEDIATE INTRUSIVE ROCKS

4 — Gabbro, quartz gabbro, hornblende gabbro and diorite

INTRUSIVE CONTACT

VOLCANIC ROCKS
Felsic Volcanic Rocks

3 — Rhyodacite and rhyolite: massive (shallow intrusive rocks); flow-breccia, tuff-breccia, agglomerate, tuff and lapilli-tuff; amygdaloidal; feldspar and quartz porphyry

Intermediate Volcanic Rocks

2 — Andesite and dacite: massive, pillowed, amygdaloidal; flow-breccia (tuff-breccia,

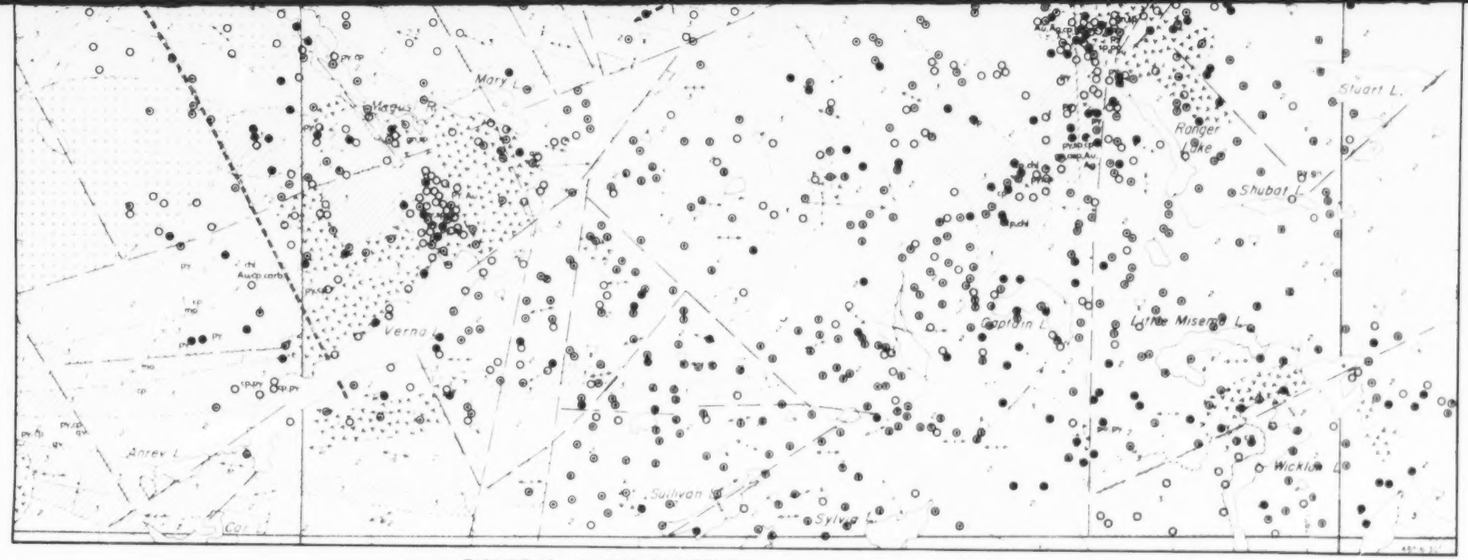


FIGURE 10 – COPPER CONCENTRATIONS IN VOLCANIC ROCKS.

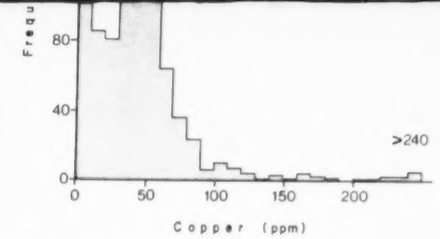


Figure 11 – Histogram of COPPER abundance in volcanic rocks.

GEOCHEMICAL SYMBOLS

- ○ Less than 30 ppm copper
- ⊙ 30-60 ppm copper
- ◉ 60-120 ppm copper
- ● Greater than 120 ppm copper

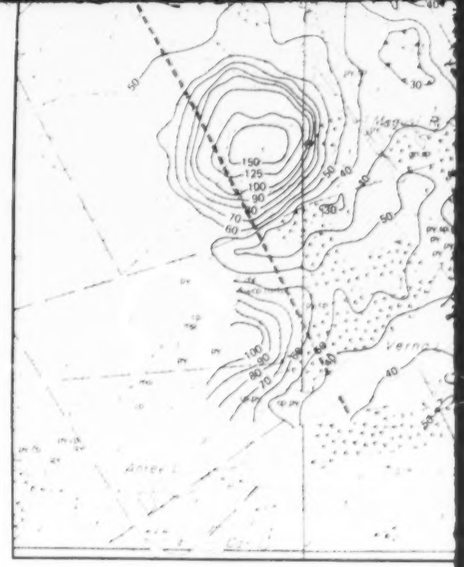


FIGURE 12

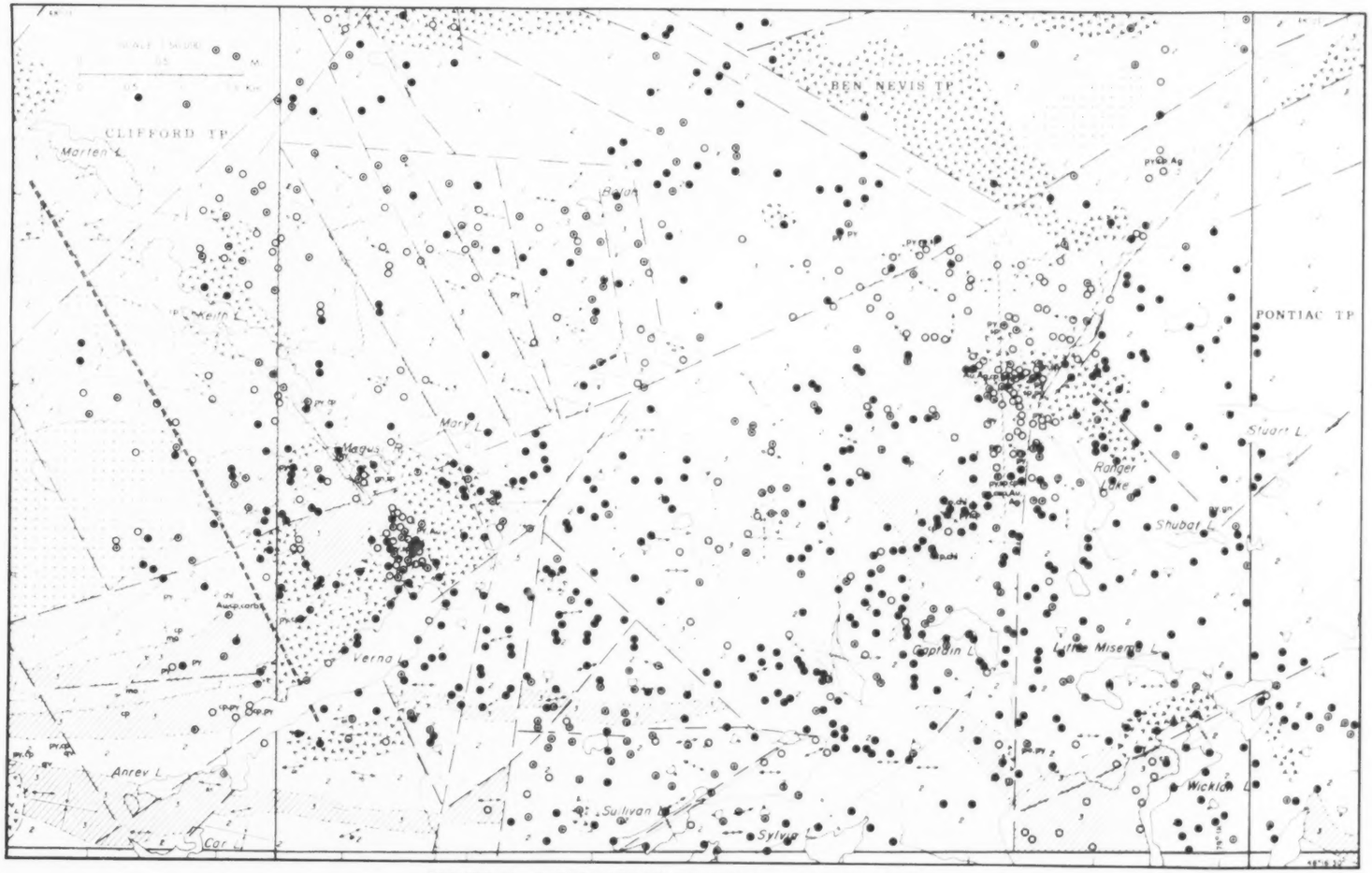


FIGURE 13 – NICKEL CONCENTRATIONS IN VOLCANIC ROCKS.

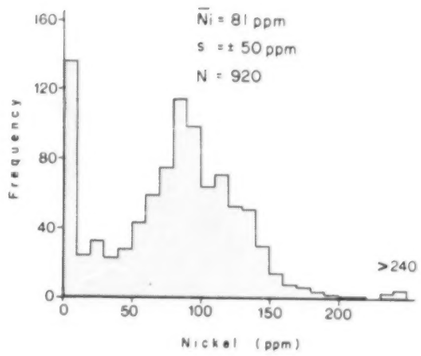


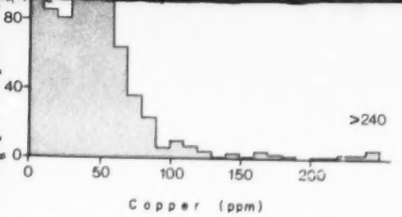
Figure 14 – Histogram of NICKEL abundance in volcanic rocks.

GEOCHEMICAL SYMBOLS

- ○ Less than 40 ppm nickel
- ⊙ 40-80 ppm nickel
- ◉ 80-120 ppm nickel
- ● Greater than 120 ppm nickel

Contours of Ni concentration (10ppm contour interval

FIGURE 15



11 – Histogram of COPPER abundance in volcanic rocks.

CHEMICAL SYMBOLS

s than 30 ppm copper

30 ppm copper

120 ppm copper

ater than 120 ppm copper

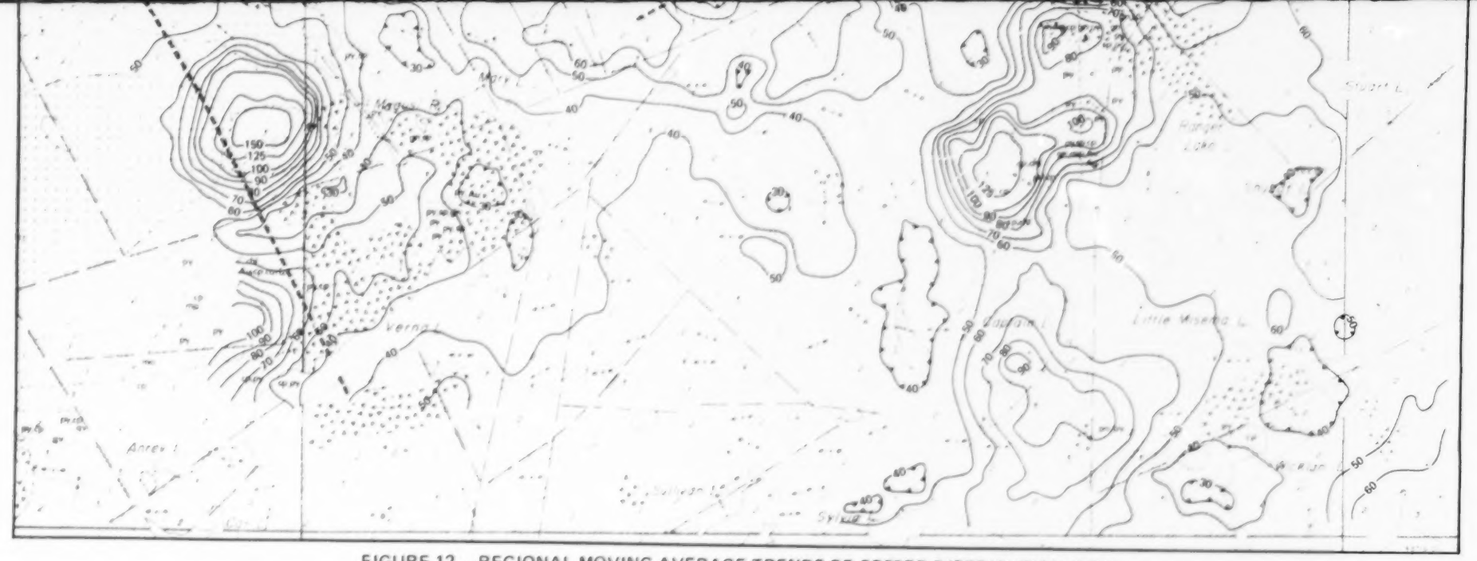


FIGURE 12 – REGIONAL MOVING AVERAGE TRENDS OF COPPER DISTRIBUTION (PPM).

Intermediate Volcanic Rocks

Andesite and dacite: massive, pillowed, amygdaloidal; flow-breccia, tuff-breccia, agglomerate, tuff; feldspar porphyry; argillite

Mafic Volcanic Rocks

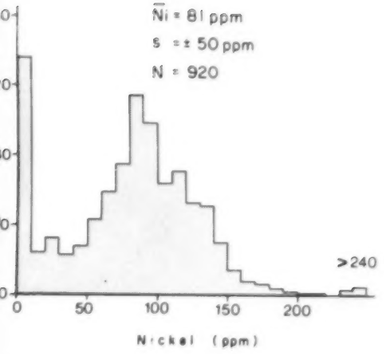
Basalt and andesitic basalt: massive, pillowed, amygdaloidal; flow-breccia, tuff-breccia; feldspar porphyry

*Not shown on this map.

GEOLOGICAL & MINING SYMBOLS

- Geological boundary.
- Lineament or fault.
- Anticline, syncline, with plunge.
- *Schistosity; (inclined, vertical).*
- Lava flow; top (arrow) from pillow shape and packing.
- Shaft.

Contours of Ni concentration (10ppm contour interval



– Histogram of NICKEL abundance in volcanic rocks.

HEMICAL SYMBOLS

han 40 ppm nickel

ppm nickel

0 ppm nickel

r than 120 ppm nickel

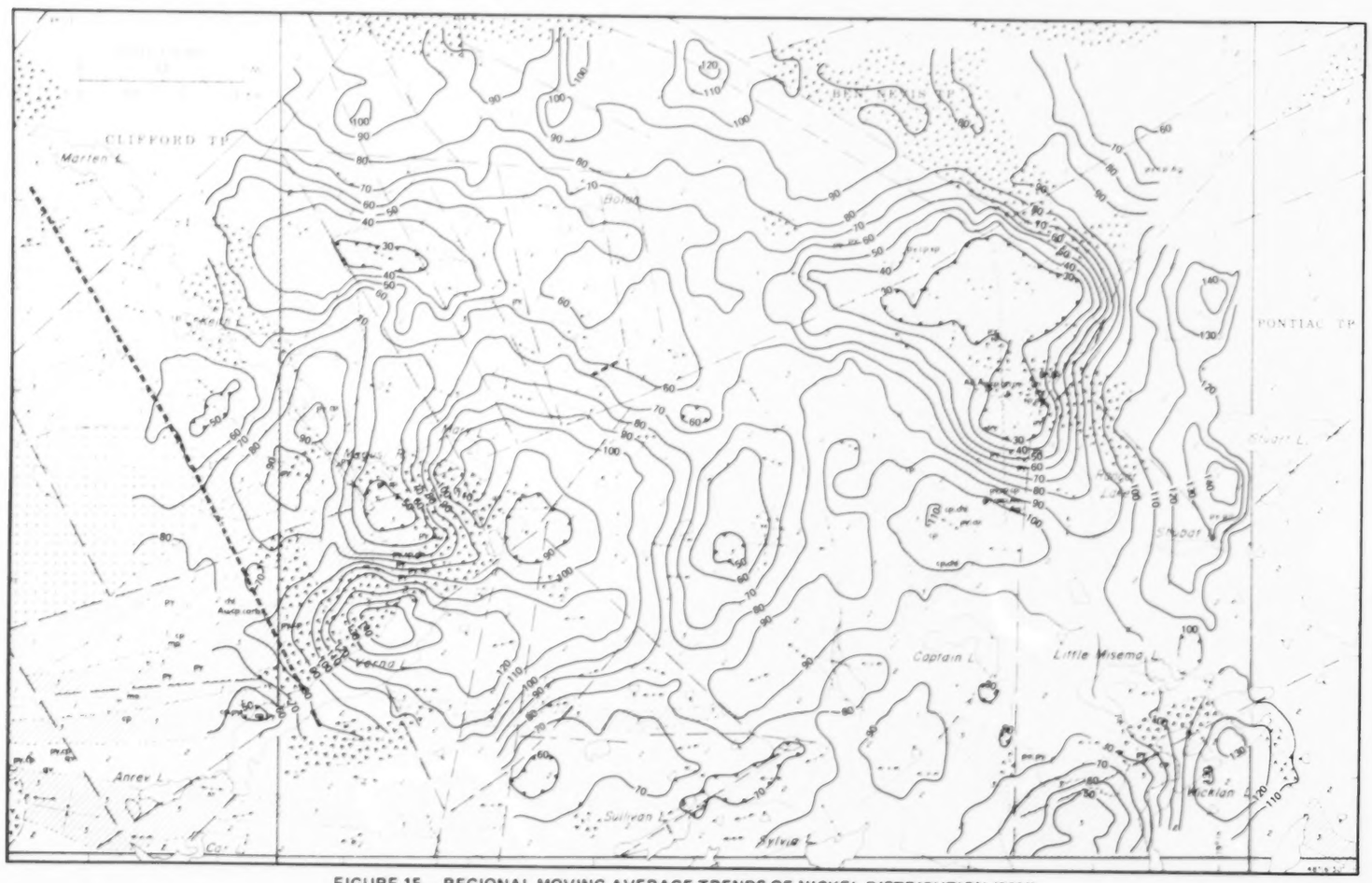


FIGURE 15 – REGIONAL MOVING AVERAGE TRENDS OF NICKEL DISTRIBUTION (PPM).

METAL & MINERAL REFERENCE

Ag	Silver
asp	Arsenopyrite
Au	Gold
carb	Carbonate
chl	Chlorite
cp	Chalcopyrite
gn	Galena
mo	Molybdenite
po	Pyrrhotite
py	Pyrite
qtz	Quartz Vein
sp	Sphalerite

SOURCES OF INFORMATION

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Magnetic declination 10°W, 1970.